OPHTHALMIC NEURO-MYOLOGY

A STUDY OF THE NORMAL AND ABNORMAL ACTIONS OF THE OCULAR MUSCLES FROM THE BRAIN SIDE OF THE QUESTION

— BY —

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PREFACE.

It has long been the desire of the author to help make the ocular muscle problem easy of solution. With this object in view he undertook the study of the normal and abnormal actions of the ocular muscles, from the brain side of the question. The results of this labor are set forth in this book, which might be entitled "The Muscle Study Made Easy;" but the title chosen is OPTHALMIC NEURO-MYOLOGY, the name implying the nature of the study.

This book is intended as a companion volume to OHTHALMIC MYOLOGY. In the light of this newer study, not a word need be changed, in the older treatise, concerning the detection and treatment of heterophoric conditions.

The hypothesis on which OPTHALMIC NEURO-MYOLOGY is founded, may be stated as follows: There are eight conjugate brain centers, in the cortex, by means of which the several versions are effected, and one conjugate center by which convergence is caused. These conjugate centers act alike on orthophoric and heterophoric eyes, and when there is only one eye. Each of these is connected with two muscles, and the work done by the center and its muscles, under the guidance of volition, is normal work. The conjugate centers have no causal relationship with the heterophoric conditions, nor have they any power for correcting them.

There are twelve basal centers, each connected with only one muscle. If the eyes are emmetropic-orthophoric, these

centers are forever at rest; but when there is any form of heterophoria, one or more of these centers must be ever active, during all working hours. These centers do not cause heterophoria, but they stand ready to correct it. Under the guidance of the fusion faculty, each basal center stands ready to act on its muscle, whenever there is a condition that would cause diplopia. They mav be called fusion centers.

If the above hypothesis accounts for every phenomenon connected with the normal and abnormal actions of the ocular muscles, as it seems to do, then it ceases to be an hypothesis and becomes a scientific fact.

Plates I to XXXVII were executed, after the design of the author, by his niece, Miss Christine Johnson, for which she deserves this public acknowledgment.

For the mechanical excellencies of the volume, the author, who is also the publisher, is indebted to the printing establishment whose inscription can be found on the title-page.

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CHAPTER I.

OCULAR ROTATIONS AND THE MUSCLES EFFECTING THEM.

The nervo-muscular mechanism, by which the eyes are moved, cannot be properly understood in the absence of a correct understanding of the globes that are to be rotated.

It is as strange as it is true that the poles of the eye have not been correctly located by previous investigators. Error in locating the poles led to the greater error of falsely locating the axes of all rotations. These errors have been pointed out in *Ophthalmic Myology*, but not so clearly nor so forcibly as the author hopes to do in this little book. A wrong beginning means a wrong ending. The error in locating the poles was in first selecting the center of the cornea for the anterior pole, and then locating the posterior pole by extending a line from the supposed anterior pole, through the center of rotation, to the retina. This line was called, or miscalled, the optic axis, or the antero-posterior axis. By it the posterior pole was located, as a rule,

between the macula and the optic disc, rarely at the macula, and more rarely still to the temporal side of the macula.

At the Saratoga meeting of the American Medical Association, in 1902, twelve of the leading Ophthalmologists present were asked this question: "At what point in the retina do all the corneo-retinal meridians cross?" With but little hesitation on the part of any one, they all answered, "at the center of the macula." In thus answering they all placed the posterior pole at the fovea centralis; for a pole is that point in a spherical surface through which all the meridians pass. Since the posterior pole is always determined by the location of the macula, it becomes evident that, in constructing the optic axis, the beginning should be made at the fovea centralis, that it should then be carried through the center of rotation, and thence to that point of the cornea through which it would pass, if prolonged, regardless of whether it be the center of the cornea, or on either the nasal or temporal side of the center. This point on the cornea is 180° from the center of the macula, or posterior pole, and it must be the anterior pole, for the two poles of a sphere are 180° degrees apart. The straight line connecting these poles is not only the true antero-posterior axis of the globe, or optic axis, but it is also the visual axis.

Every time the Javal ophthalmometer, or any other ophthalmometer, whose disc is bordered with a white band, is

used, the anterior pole is located, nearly always to the nasal side of the center of the cornea. The corneal meridians that are measured by the ophthalmometer are those lines which cross at that point of the cornea which is cut by the visual axis; for this axis is always directed to the center of the distal opening of the telescopic tube. On looking above the tube, while the patient looks into the center, the operator may find the center of the reflected disc and the corneal center the same; but as a rule the center of the reflected disc is nasal-ward from the corneal center, but wherever it is, there is the anterior pole. The ideal eye, and the best seeing eye, other things being equal, is the one whose corneal center is the anterior pole. If the anterior pole is removed more than 5° from the corneal center it is not possible for such an eye to have perfect vision for the reason that the rays of light cannot be perfectly focused on the macula. The best refracted rays are in that cone of light whose axial ray cuts the corneal center. Incidentally it may be suggested that a displaced anterior pole accounts for the fact that, in most cases, the ophthalmometer shows an excess of curvature of the vertical meridian, amounting usually to .50 D when the astigmatism is according to the rule, making it necessary to take .50 D from the cylinder. The same reasoning accounts for the fact that, in astigmatism against the rule .50 D must be added to the cylinder indicated by the ophthalmometer. In any case it

is the vertical corneo-retinal meridian which is measured. When this coincides with the curve that lies in the vertical plane which cuts the center of the cornea, there will be nothing to add to, or subtract from, the ophthalmometer reading; when it lies in the plane a few degrees removed from the vertical plane which cuts the center of the cornea, whether to the nasal or temporal side, there must be, in astigmatism against the rule, an addition to the ophthalmometer reading; likewise there must be, in astigmatism according to the rule, a subtraction from the ophthalmometer reading. The addition in the one case and the subtraction in the other case vary, as to the amount, with the distance the true anterior pole is from the center of the corneal curve. The horizontal corneo-retinal meridian has lying in it, practically always, both the anterior pole and the center of the cornea, howsoever widely these two points may be separated. It is also well known that neither addition to, nor subtraction from, the ophthalmometer reading is necessary in astigmatism in which one principal corneo-retinal meridian is at 45° and the other at 135°, for the one meridian misses the center of the corneal curve to the same extent as does the other, hence an error in the measurement of the one meridian is the same in kind and quantity as the error in the measurement of the other. To make plainer the error in measurement of the vertical corneo-retinal meridian when the anterior pole is 5° nasal-ward from the cor-

neal center, two vertical planes forming an angle of 5° should be constructed, the one cutting the corneal center, the other cutting the anterior pole, the center of rotation lying in both planes. In the latter will lie the vertical corneo-retinal meridian, and in the other will almost lie the corneal refraction curve which cuts the center of the cornea. The radius of the former corneal curve is shorter than the radius of the latter, hence the difference in the measurement of the two by the reflected images of the mires. The refraction of the corneal surface is by the curved lines whose planes all cross each other at the center of the cornea, which, as already shown, may or may not be the anterior pole. These lines should be called the *corneal refraction curves,* and not the corneal meridians, to avoid confounding them with the corneo-retinal meridians.

With the poles and the axis correctly located, the true equatorial plane is easily constructed. Since the equator is a line equally distant, at all points, from the two poles, the equatorial plane must be at right angles to the axis, and must cut it at its central point. This point in the eye is the center of rotation.

Whenever the eye is moved from one point of view to another, it takes the shortest course, that the movement may be accomplished in the quickest time, and at the least expense of nerve force and muscle energy. This being true it is clear that the visual axis has moved in a plane common

to both its first and second positions. Helmholtz's rule for locating the axis of any possible ocular rotation, whether by the action of one muscle or by the combined action of two or more muscles, must forever stand, for it is true. This is his simple rule: "The axis of any rotation of the eye is a line passing through the center of rotation, at right angles to the plane common to both the primary and secondary positions of the visual axis." It needs no further argument to show that the axis of every ocular rotation must lie in the true equatorial plane.

Listing's plane would never have been constructed if the error had not previously been made in first locating the anterior pole in the center of the corneal curve, and then finding the posterior pole by extending a line from the supposed anterior pole, back through the center of rotation, to the retina, and naming it the antero-posterior, or optic, axis. The circle equally distant from these two so-called poles could not coincide with the true equator except in an ideal eye—one whose visual axis cuts the center of the cornea—but such an eye is rarely found.

The confusion arising from wrongly locating the poles led Listing to construct his plane, a fixed vertical plane, cutting the centers of rotation of the two eyes, and then to declare that the axes of all ocular rotations lie in this plane. Helmholtz accepted the plane but rejected, in part, the teaching of Listing as to the location of the axes of rotations.

Helmholtz accepted the teaching that the axis of a rotation from the primary position to a secondary position, or *vice versa,* lies in Listing's plane, and in this he was correct; but he claimed that the axis of a rotation from one secondary position to another secondary position must lie in a plane bisecting the angle between the Listing plane and the so-called equatorial plane. The so-called equatorial plane is at right angles to that axis whose anterior pole is the center of the corneal curve; the real equatorial plane is at right angles to that axis whose posterior pole is the fovea centralis. If the angle between the true axis (the visual axis) and the false axis (the so-called optic axis) is 5°, the angle formed by the intersection of the true equatorial plane and the false equatorial plane must be 5°. In only a limited number of rotations from one secondary position to another secondary position would the true equatorial plane bisect the angle formed by the Listing plane and the false equatorial plane. Helmholtz was entirely correct in teaching that the axis of rotation from the primary to any secondary position lies in the Listing plane; he was also entirely correct when he taught that the axis of a rotation from one secondary position to any other secondary position does not lie in the Listing plane; but he was incorrect in his teaching that the axes of rotations from secondary positions to secondary positions must always lie in a plane bisecting the angle formed by the so-called equatorial plane and the

Listing plane. He was near the truth and yet did not grasp it, else he would have taught that every rotation, whether from the primary position to a secondary position, from a secondary position back to the primary position, or from one secondary position to any other secondary position, must have its axis in that movable plane which is always at right angles to the visual axis. As has been shown, this is the true equatorial plane. When the axis is in the Listing plane it is also in the equatorial plane; when the axis is not in the Listing plane it is, never-the-less, in the equatorial plane. Therefore the Listing plane has no place in the study of ocular rotations.

The Listing plane is of no value as a plane of reference, for the only two reference planes needed are the median vertical and the horizontal fixed planes of the head.

The ocular muscles and their innervation centers work in the interest of binocular single vision and correct orientation. For the accomplishment of these two purposes the muscles of the eyes are concerned only with the visual axes and the vertical axes. In the final result of their action, the recti muscles are concerned only with the visual axes, while the oblique muscles are concerned only with the vertical axes. The law governing all possible ocular rotations may be thus stated: "*The recti muscles must control the visual axes, the superior and inferior recti keeping them always in the same plane, the external and internal recti*

making them intersect at the point of fixation. The obliques must keep the vertical axes parallel with each other and with the median vertical plane of the head."

The law of rotation of a single eye may be stated as follows: *"The axis of every possible rotation, whether effected by the action of one muscle or by the combined action of two or more muscles, must lie in the movable equatorial plane and must always be fixed at right angles to the plane through which the visual axis moves from the first to the second position."*

Each of the extrinsic ocular muscles has its individual plane of action, and if each muscle acted by itself, the visual axis would move in this plane, the axis of rotation being at right angles to it. The plane of rotation of an individual muscle must pass through three points, viz.: the center of the origin and the center of insertion of the muscle, bisecting it from end to end, and the third point is the center of rotation of the eye. Only the lateral recti muscles with ideal origins and insertions, their planes coinciding with the horizontal plane of the eye, can act alone and obey the law of ocular rotations. A too high or a too low insertion of an externus or an internus would tilt the muscle plane so that it could not coincide with any meridian of the eye, and therefore its axis of rotation could not be in the equatorial plane. With such faulty attachment the internus unaided cannot rotate the eye directly in. The muscle plane of a

superior or inferior rectus does not coincide with the plane of any corneo-retinal meridian, therefore the imperious law of ocular rotations will not allow either of these muscles to act by itself, since the axis of such a rotation could not lie in the equatorial plane. The same is true of the obliques. In ideally attached muscles, rotation directly out is effected by one muscle, the externus; rotation directly in is accomplished by one muscle, the internus; rotation directly up is effected by two muscles, the superior rectus and the inferior oblique; rotation directly down is accomplished by two muscles, the inferior rectus and the superior oblique. Rotations obliquely up or down in any plane between 90° and 180° is accomplished by three muscles, two recti and one oblique, and, if it be the right eye and the rotation is up and to the right, these three muscles are the superior and external recti and the superior oblique; and if down and to the left, they are the inferior and internal recti and the superior oblique; but if it be the left eye rotating in either of these directions these muscles are, respectively, the superior and internal recti and the inferior oblique, and the inferior and external recti and inferior oblique. Rotations obliquely up or down in any plane between zero and 90°, this plane being up and to the left and down and to the right, is accomplished by three muscles, two recti and one oblique. If it be the right eye and the rotation is up these three muscles are the superior and internal recti and

the inferior oblique; and if down, they are the inferior and external recti and inferior oblique. But if it be the left eye and the rotation is up, these three muscles are the superior and external recti and the superior oblique, and if down they are the inferior and internal recti and the superior oblique.

Whenever the plane of rotation is oblique the visual axis could not move in it without torsioning the eye, if this evil effect were not counteracted by an oblique muscle. The work accomplished by the oblique muscle, in an oblique rotation, is in maintaining parallelism between the vertical axis of the eye and the median plane of the head. When the two planes of binocular rotations are between 90° and 180°, whether the visual axes are made to sweep above or below the fixed horizontal plane of the head, the torsional tendency is such as would make both vertical axes incline to the right; but this, in the right eye, is prevented by the superior oblique, while in the left eye it is prevented by the inferior oblique. When the two planes of binocular rotations are between zero and 90°, whether the visual axes are made to move above or below the fixed horizontal plane of the head, the torsional tendency is such as would make both vertical axes incline to the left; but this, in the right eye, is prevented by the inferior oblique, while in the left eye, it is prevented by the superior oblique.

The supreme law of binocular rotations is the law of cor-

responding retinal points. To so relate the two retinas that they may receive, on corresponding parts, the two images of the single object, the superior and inferior recti must keep the two visual axes in the same plane; the internal and external recti must converge these axes at the point of fixation; and the obliques must keep the vertical axes parallel with the median plane of the head. These conditions must exist whether the object of view is immediately in front, or directly above or below the extended horizontal plane of the head, or directly to the right or left of the extended median plane of the head, or in any oblique position. It is no less true that these conditions must be maintained when the two eyes are being rotated from any one point to any other point in the field of vision. That this may be true every rotation plane must be a meridional plane extended, and every axis of rotation must lie in the equatorial plane. *Every rotation plane is a fixed plane, for in it lie three fixed points, viz.: the first and second points of view and the center of rotation.* If, in oblique rotations, the eyes were allowed to tort, as taught by Listing, the rotation plane, which is an extended meridional plane, would also tort, therefore it could not be a fixed plane.

Correct orientation, as well as binocular single vision, demands that ocular rotations shall be in meridional planes, and that the axes of all rotations shall lie in the equatorial plane.

If the eye can be rotated in a meridional plane by a muscle, only that one muscle will be called into action; if the united action of two muscles will cause an eye to rotate in a meridional plane, then only these two muscles will be excited into activity. All rotations in oblique meridional planes are effected by the conjoined action of three muscles, and only three.

Every muscle has two properties, viz.: tonicity and contractility. A muscle, in a perfect state of rest, manifests its tonicity; a muscle excited by receiving a charge of neuricity, exhibits its power of contractility. Tonicity may be termed latent power; contractility is manifest power. Tonicity is rest; contractility is action. Alternate rest and action tend to preserve the healthfulness of muscles. Too much contraction of a muscle (overwork) impairs its tonicity; too much rest enfeebles the contractile power of a muscle.

The muscles of the two eyes must work in harmony and with mathematical exactness. They work in pairs, and one muscle of every pair is connected with each eye. To effect the right rotation of the eyes, the right externus and left internus constitute a pair; in the left sweep of the eyes, the left externus and the right internus constitute a pair; in the act of convergence the two interni constitute a pair. In the upward sweep of the eyes the two superior recti constitute a pair, and in this they are aided by the two inferior

obliques constituting another pair. In the downward sweep of the eyes the two inferior recti constitute a pair, and as helpers in this movement the two superior obliques constitute a pair. In oblique rotations up and to the right, the right externus and left internus constitute a pair, the two superior recti constitute a pair, and the right superior oblique and the left inferior oblique constitute another pair. In rotations down and to the left, the left externus and the right internus make one pair, the two inferior recti make one pair, and the right superior oblique and left inferior oblique make another pair. In oblique rotations up and to the left, the left externus and right internus make one pair, the two superior recti make one pair, and the left superior oblique and right inferior oblique make another pair. In oblique rotations down and to the right, the right externus and the left internus make one pair, the two inferior recti make one pair, and the left superior oblique and right inferior oblique make another pair. These various rotations are accomplished with the greatest ease if the muscles concerned have their normal tonicity—if there is orthophoria.

TONICITY.

The study of tonicity of the muscles must likewise be made in pairs, but the two muscles constituting any pair belong to the same eye. With the head in the primary position, the superior and inferior recti possessed of ideal

tonicity would cause the visual axis to lie in the extended horizontal plane of the head, when unexcited by neuricity from either the cortical or basal centers controlling them. The internal and external recti whose tonicity is ideal would place the visual axis parallel with the extended median plane of the head, when uninfluenced by neuricity from either cortical or basal centers. The superior and inferior obliques with ideal tonicity would make the vertical axis parallel with the median plane of the head although uninfluenced by neuricity from either basal or cortical centers. These statements being true, it becomes self-evident that if the tonicity of a superior rectus be greater than that of the inferior rectus of the same eye (hyperphoria), the visual axis would be elevated above the extended horizontal plane of the head, and if the tonicity of the inferior rectus be greater than that of the superior rectus of the same eye (cataphoria) the visual axis would be depressed below the extended horizontal plane of the head. In either case, that there may be binocular single vision, the muscle with less tonicity must receive a certain amount of neuricity from its proper basal center, that contractility may be made to supplement tonicity and thus make the weaker muscle evenly balance the tonicity of the stronger muscle.

In like manner it becomes evident that, if the tonicity of the externus is greater than that of the internus of the same eye (exophoria) the visual axis would be made to point

from the extended median plane of the head; and if the tonicity of an internus is greater than that of the externus of the same eye (esophoria), the visual axis would be made to point *towards* the extended median plane of the head. In either case, that there may be binocular single vision, the muscle wanting in tonicity must receive a definite quantity of neuricity from its proper basal center, that contractility may supplement its tonicity and thus make it equal, in power, the tonicity of the stronger muscle. With the visual axis lying in the extended horizontal plane and parallel with the extended median plane of the head, the oblique muscles, if equal in tonicity, would parallel the vertical axis with the median plane. If the tonicity of the superior oblique should be greater than that of the inferior oblique of the same eye (minus cyclophoria), the vertical axis would be inclined toward the median plane of the head; if the inferior oblique should have the greater tonicity (plus cyclophoria), the vertical axis would deviate from the vertical plane of the head. In either condition, whether the vision is monocular or binocular, the weaker muscle must receive neuricity from its proper basal center that contractility may be excited to supplement its tonicity in the work of paralleling the vertical axis with the median plane of the head.

The tonicity of the recti muscles would demand but little study if there were only one eye, for the visual axis might

form any angle with either the extended vertical or horizontal planes of the head without interference with orientation. A posing of the head, therefore, would compensate for any difference in tonicity between the members of either pair of recti muscles, in persons possessed of only one eye. Unequal tonicity of the obliques, in a one-eyed person, cannot be counteracted so easily by any pose of the head, therefore the demand on these muscles would be just as great if there were only one eye as when there are two. Correct orientation depends on perfect parallelism of the vertical axis of the eye with the median plane of the head. This law is infringed only in the interest of binocular single vision, and then only in cases of non-symmetric oblique astigmatism.

In binocular vision the importance of the study of the tonicity of the ocular muscles cannot be over-estimated. It is easily within the power of every ophthalmic surgeon to become a master in this study. To determine the tonicity of either the recti or the obliques, care must be exercised to avoid, as far as possible, a flow of neuricity from any cortical center, and that all basal centers shall be perfectly quiet. In well balanced emmetropic eyes there is no activity of either cortical or basal centers, when the head is in the primary position, the visual axes lying in the extended horizontal plane of the head and being parallel (or practically so) with the extended median plane of the head. When these conditions are met, and the two eyes are heterophoric

but emmetropic, all the volitional centers, to be studied further on, must be free from any demand for neuricity, hence no muscle contraction can come from that source. It only remains to put at rest the basal centers which are under the control of the fusion faculty of the mind. This is done by producing insuperable diplopia. Fusion having been rendered impossible by the displacing prism, no fusion or basal center will be called into action, hence no muscle contraction can come from that source.

The only wholly trustworthy instrument for placing the fusion centers at rest, and detecting and measuring errors of tonicity in the recti muscles, is the Monocular Phorometer. The displacing prism of this instrument must throw the image in the eye before which it stands, entirely outside the retinal fusion area. The other eye, before which no part of the instrument is placed, must fix the test object seen by it, and the test object must be so related to this eye that its visual axis and the object shall lie in the extended horizontal plane of the head. If the false object has been displaced laterally and the superior and inferior recti of the two eyes have equal tonicity, the false and the true objects will be in the same horizontal plane; but if the superior rectus of the eye under test has greater tonicity than its inferior rectus (hyperphoria), the false object will be seen lower than the true object. The rotary prism can be made to lift the false object into the same plane with the true,

when the index will show the degree of the error. But the amount of the error thus measured is in excess of the true error, as can be easily shown. The inferior rectus of the fixing eye having greater tonicity than its superior rectus, the two muscles in a state of rest would cause the visual axis to be depressed. To bring this axis into the horizontal plane the cortical center that controls the upward sweep of the eyes must be excited into activity, the result being a contraction of both superior recti. As will be shown, this center sends the same quantity of neuricity to one of these muscles that it sends to the other. The greater tonicity of the superior rectus of the eye under test would elevate its visual axis above the extended horizontal plane of the head, but the contractility excited by the neuricity sent equally to the two superior recti, makes the visual axis of this eye move faster and rise higher than the other, and throws the false object correspondingly lower. Thus would be shown a greater deviation tendency than really exists. This explains what experience has taught, that a full prismatic correction should not be given when a vertical deviation tendency is to be treated by a prism in position of rest.

In testing the tonicity of the external and internal recti the head must be in the primary position, and the test object should be at practical infinity and in the line of intersection of the extended median and horizontal fixed planes of the head. The displacing prism with its base up before one

eye should be sufficiently strong to throw the image of the test object in that eye entirely outside the fusion area, so as to place in absolute rest the basal or fusion centers. If the lateral recti are possessed of equal tonicity, the false object will be below the true but in the same vertical plane; but if the tonicity of the interni is greater than the tonicity of the externi (esophoria), the false object, if seen by the left eye, will be to the left of this plane. The rotary prism measures the amount of this deviation by bringing the false object directly under the true. The measurement, however, is in excess of the true error for this reason: the internal rectus of the fixing eye (in this instance the right eye) being possessed of greater tonicity than its externus, the restful state (tonicity) of these muscles would make the visual axis point towards the extended median plane. The fourth cortical center, which controls the right sweep of the eyes, must send neuricity to the right externus so as to add contractility to its tonicity and thus place the visual axis parallel with the median plane. The fourth cortical center, thus excited, sends an equal amount of neuricity to the left internus, and this muscle having greater tonicity than the right externus, responds more powerfully and rotates its eye faster and further under the equal stimulus, and thus throws the false object correspondingly too far from the median plane. To avoid this error in measurement the test object should be on the visual axis of the fixing

eye, its lateral recti being in the restful state, but it would be impossible to determine this position in any case. This error in measurement, when the head is in the primary position and the test object properly placed, may be much or little, depending on the difference in tonicity of the two muscles controlled by the excited cortical center.

With the head in the primary position, the test object in the line of intersection of the extended median and horizontal planes of the head and at practical infinity (thirty feet would be better than twenty), with the false image thrown entirely outside the retinal fusion area, and the free eye used for fixation, the measurement of any deviation will be more or less in excess of the true error, but this measurement will not vary from day to day, except under treatment. Non-observance of these details accounts fully for the complaint of some that the measurements of muscle errors vary from time to time. The binocular phorometer may be another cause of variation in measurements.

Tonicity of the Obliques.—The test, or tests, for determining the tonicity of the obliques should be made when both the head and eyes are in their primary positions. The test object may be a horizontal line on a black board, twenty feet distant, or a horizontal line on a card to be held at the reading distance. The means for making this test may be a single prism of 6 degrees taken from the test case. This prism should be placed, base up, before one eye. Fixing the

real line with the other eye, the image of the line in the eye under test will lie entirely above the retinal fusion area, and no attempt at fusion will be made. The non-fixing eye —the one under test—will assume at once that position in its orbit in which the tonicity of the recti and the obliques would place it. If the obliques of this eye are well balanced, if they have equal tonicity, the false line will be parallel with the true one; if the superior oblique has less tonicity than the inferior, the false line will dip towards the opposite side, the two lines appearing to be wider apart at the ends corresponding to the eye not under test; if the inferior oblique has less tonicity than the superior, the false line will dip towards the corresponding side, the lines appearing to be closer together at the ends corresponding to the eye not under test. If the line seen by the eye not under test is constantly fixed, it will remain horizontal, however much the false line may incline, and for the reason that the image of the former lies wholly in the retinal fusion area, thus compelling the obliques of this eye, though unequal in tonicity, to parallel the vertical axis with the median plane of the head. Under the single prism test, cyclophoria can be detected easily and its kind determined, but its quantity cannot be measured.

The use of the Maddox double prism is neither easier nor more accurate than that of the single prism. The double prism is of interest, however, for the reason that it was the

means that resulted in the discovery of cyclophoria in 1890, just fifteen years ago. The author made his first publication on unequal tonicity of the obliques in the Archives of Ophthalmology, January, 1891, under the caption, "Insufficiency of the Obliques." The accompanying figures 1, 2, 3 and 4 were used to illustrate that paper, and the following language was used in the text: "Place a double prism, axis vertical, before one eye, the other for the moment being covered, and ask the patient to look at a horizontal line on a card held sixteen inches away. The effect of the double prism (each 6°) is to make the line appear to be two, each parallel with the other. The other eye is now uncovered, and a third line is seen between the other two, with which it should be perfectly parallel.

"If there is a want of harmony on the part of the oblique muscles [unequal tonicity], this test will show it at once in a want of parallelism of the middle line with the two other lines, the right end of the middle line pointing towards the bottom line and the left end towards the top line, or *vice versa,* depending on the nature of the individual case.

"Consider the eye before which no prism is held as the one under test. With the double prism before the right eye, the patient is asked about the position and direction of the middle line. It may be nearer the bottom line, thus showing left hyperphoria; or, again, it may extend further to the right than the other two, and not so far to the left, thus

showing exophoria; or, *vice versa,* showing esophoria. If the right ends of the middle and bottom lines converge while the left ends diverge, the superior oblique of the left eye is at once shown to be in a state of underaction [wanting in tonicity]. Figure 1 represents such a test of the left eye; Figure 2 shows a test of the left eye where the inferior oblique is the too weak muscle; Figure 3 represents a test of the right eye, the loss of parallelism between the lines being due to underaction of its superior oblique; Figure

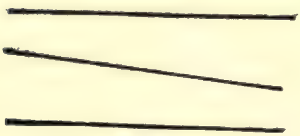


Fig. 1.

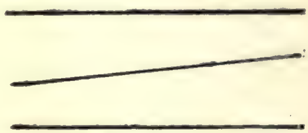


Fig. 2.

4, the same condition of the inferior oblique of the right eye."

The changes that the author would make in the language then used, if he were now speaking, for the first time, of the double prism test for determining the tonicity of the obliques, would be to substitute "cyclophoria" for "insufficiency of the obliques," "wanting in tonicity" for "underaction." He would also emphasize the importance of fixing either the top or the bottom line, so that the eye seeing the middle line may assume the position allowed by the tonicity of all its muscles. As with the single prism, so with the

double prism, cyclophoria can be detected and classified, but cannot be measured.

The rotary prism can do only what can be done by the single and double prisms—that is, detect and classify cyclophoria without measuring the quantity. To make the test with the rotary prism it should be adjusted as for taking sub- and superduction. Rotating it up or down, beyond the point of possible fusion, the test line becomes double. The eye seeing the true line should be the fixing eye, as in the

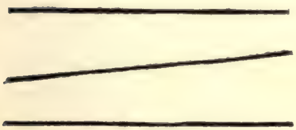


Fig. 3.

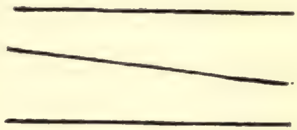


Fig. 4.

test with the single prism. If the tonicity of the obliques is normal the two lines will be parallel; if the superior obliques are wanting in tonicity the false line will dip towards the opposite side; if the inferior obliques are wanting in tonicity the false line will dip towards the corresponding side. Revolving the rotary prism towards zero will make the two lines approach and finally fuse. If the false image is below and is seen by the right eye, as the rotary prism is moved toward zero the right ends of the lines will fuse first in plus cyclophoria, and the left ends will fuse first if there is minus cyclophoria. If there is no cyclophoria the two lines will

fuse throughout their entire length at the same moment. The convenience with which the rotary prism can be used makes it more desirable than the single prism from the trial case.

The cyclophorometer will detect, classify and measure cyclophoria. This instrument should be perfectly leveled and the index of each rod must stand at zero. Behind the right rod a 6° prism should be placed base up, and behind the other rod, unless it be a red one, should be placed a plane red glass. The room should be made dark, and the test object should be a candle, or better still, a point of light. The left or fixing eye would see a red streak of light perfectly horizontal, and the right eye would see a yellow streak of light below the red one. The ends should be made even by the adjustment screw and then the patient should be asked if the two streaks are parallel, as they would be if there is no cyclophoria. If the yellow streak dips towards the left there is plus cyclophoria. The divergence of the lines to the left is corrected by revolving the disc before the right eye, in the upper temporal quadrant,* sufficiently far to bring the false streak into the horizontal position, hence into parallelism with the red or true streak of light. The index, pointing to a degree mark on the scale, will show the amount of plus torsioning that has occurred.

* The cyclophorometer as now made has the scale in the upper semicircle. In the first instruments made the scale was in the lower semicircle. The latter is the one spoken of in OPHTHALMIC MYOLOGY.

This application of the Maddox rod was first made by Dr. Price, Nashville, in 1894. The discs containing the rods were shown by him at the San Francisco meeting of the American Medical Association in that year. The one disc was an unmodified Maddox triple rod, but behind the triple rod in the other disc was a double prism. This arrangement gave three streaks of light, two seen by one eye and one by the other eye. The two disc were set in ordinary trial frames the leveling of which could only be approximated. It was soon observed that two streaks of light were all that were necessary, hence the double prism combination has been abandoned and a single prism substituted. Out of the Price device was evolved the author's cyclophorometer, which can be used in both the tonicity and the duction tests of the obliques.

The clinoscope devised by Stevens not earlier than 1896 and probably not until 1897, is capable of detecting, classifying and measuring cyclophoria, which Stevens is better pleased to term retinal declination, although the term cyclophoria had been previously given us by Price in conformity with the Stevens nomenclature concerning the recti muscles. The tonicity test with the clinoscope should be made, preferably, by using the two opaque discs that contain each a diameter. These discs should be so placed at the distal end of the tubes that the lines would be horizontal. At the proximal end of one tube should be placed a 6° prism, base

up. The one line would be thrown so far below the other that no attempt at fusion would be made. If the indices now stand at zero, the two lines should be parallel. Fixing the gaze on the upper line, if the bottom line is not parallel with it, the tube showing the dipping line should be revolved so as to make the displaced line parallel with the other. The index pointing outward would show plus cyclophoria, and the degree mark at which the index stands shows the quantity of the error.

The factors entering into the causation of cyclophoria are fully set forth in "*Ophthalmic Myology.*" The condition is one and the same by whatever name it may be called, whether "insufficiency of the obliques" (Savage), "cyclophoria" (Price), "torsion" (Maddox), or "retinal declination" (Stevens).

CONTRACTILITY.

There are three tests for determining the contractility of the ocular muscles. The first is for measuring the voluntary contraction of the muscles when made to move the eyes in either of the four cardinal directions; the second is to ascertain the power of convergence; and the third is to find the fusion power of a muscle.

VERSION.—The muscular power that turns the eyes in either of the four cardinal directions is volitional, and the neuricity that causes the contraction of the muscles concerned comes from centers in the cortex of the brain. No

better name could be given this power than "version," especially since it so easily combines with prefixes that indicate the direction of the turning, as abversion, adversion, subversion and superversion. If the internus and the externus have the same tonicity, adversion and abversion will be equal; if there is greater tonicity of the internus than there is of the externus, adversion will be greater than abversion; but if the externus has an excess of tonicity, abversion will be greater than adversion. The normal verting power of an externus or an internus is about 50°. Normal subversion and superversion is also about 50° each, though superversion is given by most authors as much less, usually about 33°. This low superversion is probably due to the fact that the test object becomes obstructed by the over-arching brow, and thus causes the eye to lose the stimulus for further rotation. The best means for determining the verting power of a muscle is the Stevens tropometer. One eye should be covered while the other is under test. The perimeter may be used, but its use is neither so easy nor accurate as the tropometer. In using the tropometer or the perimeter, the verting power of only one muscle of one eye is studied at a time; and in this study it is better to use the terms adversion and abversion, in expressing the rotation power of the interni and externi, than to say right version and left version. It must be remembered, however, that the center sending forth the neuricity that causes abversion of one eye causes,

at the same moment, adversion of the other eye, the latter being equal in extent and rapidity to the fórmer, if the lateral muscles are orthophoric.

The power to turn the two eyes in the same direction, at will, is given us, that the point of view may be changed, in a large part of the field of vision, without moving the head or body. The centers effecting these rotations do not exist in the interest of binocular single vision in the sense that they are presided over by the fusion faculty of the mind, for, as already stated, they are volitional centers. Each center influences equally two muscles, one belonging to each eye, but not always with the same result, the difference in result depending on a difference in the tonicity of the two muscles concerned. If the two muscles are orthophoric—equal in tonicity—the center calling them into action will effect the rotation without diplopia or a tendency towards its production. If the two muscles are heterophoric—unequal in tonicity—the center exciting them would cause the stronger muscle to rotate its eye further and faster than the weaker muscle would rotate its eye, and diplopia would result, except for nature's wonderful provision for preventing it. This provision is the basal center, presided over by the fusion faculty of the mind, which stands ever ready to send a supplemental charge of neuricity to the weaker muscle in order than there may be harmonious rotation of the two eyes. In uncorrected heterotropia, binocular single vi-

sion is impossible, but, notwithstanding this, the volitional verting centers cause the eyes to rotate as if they were seeing together; and the same is true when one eye is blind. The verting centers do the same kind of work whether the eyes are orthophoric, heterophoric or heterotropic, and even when one of the two eyes is blind from disease. Thus it must be true that the volitional centers that control the verting function of the muscles have nothing to do in the work of correcting heterophoric conditions. Nor do these centers bear any causal relationship to heterophoria in any of its forms. These centers are conjugate because they join in action two muscles, one belonging to each eye; they are volitional centers, for no one looks either to the right, the left, up, down or in any oblique direction, without first willing to do so. These centers are all in the motor area of the cortex, and may be named, arbitrarily, the first, second, fourth, fifth, sixth, seventh, eighth and ninth conjugate centers. These centers, with the exception of the second and sixth, are excited into activity for only a short period at a time, the gaze rarely being prolonged in any oblique direction or in any cardinal direction, except down. Prolonged downward look is common; and during this time the second and sixth centers are in continuous action, usually in association with activity of the third conjugate center, or center of convergence, which is also a volitional center. Civilization has added but little, if any, to the work of the

first, fourth, fifth and seventh volitional centers, but it has created immense demands on the second, third, sixth and tenth volitional centers. These latter centers must be continually discharging neuricity to the inferior and internal recti, the superior obliques and the ciliary muscles, respectively, throughout the continuance of near work; nor can any pose of the head bring the slightest relief to the third and tenth centers. Dropping the head forward, its usual pose in reading, relieves to a greater or less extent the second and sixth centers, the relief being complete when the horizontal plane of the head has been so depressed as to be at right angles with the printed page. Reading in the recumbent posture adds nothing to the work of the third and tenth centers, but it adds immensely to the work of the second and sixth centers. The third and tenth centers have rest only when near work has been interrupted by closing the eyes, or by looking into infinity. From what has just been said it would appear that reading or other near work should never be done by one in the recumbent posture; that, when the body is erect, the head should be inclined forward so that its horizontal plane extended might point towards, if not to, the printed page or other object of near vision, for the relief of the inferior recti and superior obliques and the second and sixth centers that innervate them; that frequent, even if short, intervals of rest should be given the internal recti and the ciliary muscles and the third and

tenth centers that control them, by closing the eyes or by changing the point of vision to some distant object in or above the horizon. If these rules are not observed, near work cannot be done so comfortably nor so efficiently.

Convergence.

Convergence pertains only to the internal recti, but it is normally associated with accommodation. Its center, the third conjugate, is situated in the cortex and is under the control of the will. No better name could be given this power than convergence. The angle of convergence is that formed by the intersection of the two visual axes, and at one metre is twice the so-called metre-angle of Nagel. The distance (base line) between the centers of the two eyes being two inches, the true metre-angle (the angle of convergence at one metre) is 2° 54′ 38″. For every increase of the base line by one-eighth inch the metre angle is increased 10′ 55″. The angle of convergence at two metres is one-half a metre angle, and convergence at one-half a metre is two metre angles. But it is not so important to know the angle of convergence as it is to study the ease with which it may be accomplished. The third cortical center is the one controlling convergence. This center is so intimately associated with the tenth cortical center, the one controlling the ciliary muscles, that they may be said to act as if the two constituted one center. Normal ciliary muscles and perfect

balance of the externi and interni can mean nothing else than harmonious accommodation and convergence.

Weak ciliary muscles and normal lateral recti muscles mean inharmonious accommodation and convergence. Normal ciliary muscles and weak interni mean want of harmony between accommodation and convergence. Necessity for ciliary activity for distant seeing, as in hyperopia, causes a corresponding contraction of the interni, which would cause convergence except for activity of the basal centers governing the externi. In general terms it may be stated: for every accommodative diopter of neuricity discharged by the tenth cortical center, a corresponding convergence diopter of neuricity is discharged by the third cortical center. The normal discharge of neuricity by the tenth center for effecting 3 D of accommodation in emmetropic eyes, may be stated to be three diopters, and the same quantity discharged by the third center should produce the necessary convergence (three metre angles). If more is needed because of want of tonicity of the interni, supplemental neuricity is sent from the right and left third basal centers; if, because of too great tonicity of the interni, the three diopters of neuricity from the third cortical center would cause too much convergence, this effect would be counteracted by a discharge of neuricity from the right and left fourth basal centers to the externi. If the ciliary muscles, because of inherent weakness, should need six diopters of neuricity for

effecting 3 D of accommodation, the third cortical center would also discharge six diopters of neuricity to the interni and these, having normal tonicity, would be excited into over-action. Excessive convergence would be prevented only by excitation of the right and left fourth basal centers calling into corrective action the two externi.

Carrying a test object towards the two eyes, to determine how near it may be made to approach them without relaxation of convergence, is of no practical value; though it is well known that some eyes can attain a greater angle of convergence than others. It is also known that, as a rule, the greater the accommodative power the larger the possible angle of convergence; and yet it is well known that presbyopia has but little influence over convergence. Failure of ciliary power, because of age, and convergence still active; dissociation of accommodation and convergence, in the young, by convex lenses or by prisms; and myopia and convergence, these would all seem to argue against the idea that the third and tenth conjugate centers act as if only one center. It may be that, in presbyopia, the tenth center continues to send neuricity to the ciliary muscles, although they may be no longer able to respond, while the neuricity from the third center gets ready response from the interni. Over-convergence, when the eyes are going under the influence of a mydriatic, can be explained in no other way than that the maddened tenth center generates and discharges an

excess of neuricity to the muscles whose power is waning, and that a corresponding excess of neuricity is sent to the interni. There seems to be but little room for doubting that, in the young at least, the third and tenth conjugate centers are most intimately associated in action.

The convergence test should be made with the monocular phorometer at the reading distance, and the dot, or other test object, should be held in the line of intersection of the extended median and horizontal planes of the head. The free eye should be the one used in fixation, and with this eye the patient should look sharply at the true object. The displaced image in the other eye makes fusion impossible, nevertheless there will be convergence, the angle depending on these two conditions, viz.: first, tonicity of the ciliary muscles and of the interni; second, the quantity of neuricity discharged by the third and tenth cortical centers. The false image having been thrown entirely outside the retinal fusion area, the fusion faculty cannot excite any of the basal centers. If, in the distant test, lateral orthophoria has been shown, the false object should be directly under the true in the near test. If the convergence is too great (pseudo-esophoria), it shows that the tonicity of the ciliary muscles is too low, and that they demand an excessive amount of neuricity from the tenth conjugate center for effecting the necessary accommodation. This over-excitation of the tenth center causes a corresponding over-excitation of the third

conjugate center, hence over-action of the interni (pseudo-esophoria). Or if the tonicity of the interni is too high (sthenic orthophoria), the normal quantity of neuricity from the third cortical center excites too much contractility. In either case the pseudo-esophoria would be shown. Such eyes, when engaged in near work, are prevented from crossing by excitation of the right and left fourth basal centers, which call into corrective or fusional activity the two externi.

When the near test shows want of convergence, or pseudo-exophoria, the distant test having revealed orthophoria, one of two conditions exists: first, the ciliary muscles have high tonicity and demand less neuricity than normal for effecting accommodation, hence the third conjugate center fails to furnish enough neuricity to effect the required convergence; or, second, the tonicity of the interni is low (asthenic orthophoria), and the normal impulse sent from the third conjugate center fails to make them converge the visual axes sufficiently. In either case the near use of such eyes makes it necessary for the fusion faculty to bring into action the right and left third basal centers, that enough convergence may be had. Unlike the volitional centers that control version of the eyes, the convergence center, as already shown, may cause one form of heterophoria, viz., pseudo-heterophoria, which may be either pseudo-esophoria or pseudo-exophoria. The former may be shown in both the far and

near phorometric tests, but the latter can be shown only in the near test.

The third cortical center, or center of convergence, is sometimes absent, as is shown by inability to converge, although right and left versions are normal.

DUCTION.

Of the three kinds of power of the ocular muscles, the duction power is the most important, when there are two eyes, for this power exists only in the interest of binocular single vision. While the centers that effect version and convergence are situated in the cortex and each one is connected with two muscles, one belonging to each eye, and these centers are under the control of the will, the duction centers are basal, and each is connected with only one muscle, and they are controlled by the fusion faculty of the mind. These centers always stand ready to send supplemental neuricity to either muscle of a pair wanting in tonicity. They also stand ready to lead the eye into a proper position for placing the macula under a displaced image; or, if both images have been displaced, the duction power will be excited so as to place the macula of each eye under its proper image. There is, in each eye, a field on any part of which other than the macula one of the two images of an object may fall, the other image being on the macula, and yet produce only temporary diplopia; for the fusion faculty, having the mastery

of this field, as well as of the basal centers, calls into activity one or more of the basal centers for leading the eye into a position that will place its macula under the image.

The fusion field of the retina can be mapped out with a high degree of accuracy, and this field always includes the macula. Measuring from the macula along the horizontal meridian, the nasal extent of this field is about 8° of prism,

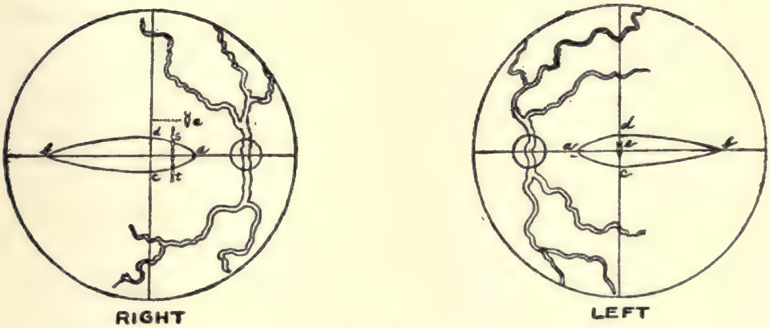


Fig. 5.

and the temporal extent of the field is 25° to 35° of prism; but above and below the macula, along the vertical meridian, this field measures only about 3° of prism. Connecting each of the two points on the horizontal meridian, marking the nasal and temporal limits of the fusion field, with the two points on the vertical meridian, marking the upper and lower limits of this field, an area will be included somewhat kite-shaped, the tail of the kite being towards the

temple, while the head of the kite is towards the nose. This area is the retinal fusion field. The two images of an object of fixation can be fused only when they fall on the maculas. If one of the images is on the macula, and the other image on some other part of the fusion area, the object is doubled until the eye, seeing the false object, is led into such a position as will place its macula under the misplaced image. This accomplished, the two eyes see only one object, but only one eye is pointing towards it. If the misplaced image is thrown on a part of the retina entirely outside the fusion area, no attempt is made to fuse the two images, and the object remains double, but both eyes point towards the true object.

Even in orthophoria a study of the duction power of the muscles is important, for while the two muscles of a pair may be equal in tonicity, both may be wanting in contractile power. This want can be detected more easily by the duction test than by the version test.

In heterophoria the muscle that is stronger than its antagonist may not possess in itself too much contractile power, and this is better shown by the duction test than by the version test. In no case of heterophoria can the proper treatment be resorted to without a knowledge of the duction power of the muscles concerned. In a case of exophoria, the externus should not be weakened by a partial tenotomy unless its duction power has been shown to be more than

8°; unless abduction has been ascertained to be less than 6° or 8°, a shortening or advancement of an internus should not be done for an exophoria.

Normal abduction, or the power that an externus has to lead its eye so that the macula may be brought under an image that has been displaced toward the nose, in the field of fusion, is 6° to 8°. The neuricity that causes this contractility comes from the fourth basal center on the corresponding side.

Normal adduction, or the power that an internus has to lead its eye into a position that will place the macula under an image that has been thrown towards the temple, in the fusion area, is 25° to 35°. This power comes from the third basal center on the corresponding side.

Normal superduction, or the power that a superior rectus has to so lead its eye that the macula may be brought under an image that has been displaced downward, in the fusion field, is 2° to 3°. The impulse causing the contractility comes from the first basal center on the same side.

Normal subduction, or the contractile power that an inferior rectus has for leading its eye into a position that will place its macula under an image that has been displaced upward, in the fusion field, is 2° to 3°. This movement is effected by the neuricity from the second basal center on the corresponding side.

The above duction measurements presuppose normal

tonicity of the muscle measured, and that its basal center is likewise normal in that it is under the perfect control of the fusion faculty of the mind. The cause of any variation from these measurements resides either in the muscle or in the basal center that controls it. If there is an excess of duction power and the cause is in the muscle itself, there is too much tonicity due to excess in size, or to the fact that its attachment to the globe is in front of the usual line of attachment; if the cause of the excess is in the basal center that excites the contractility, the only explanation is that the center is capable of storing and discharging an abnormally large quantity of neuricity. If the duction power is less than normal and the cause resides in the muscle, it is because the muscle is too small or that its attachment to the globe is behind the normal line of attachment; but if the cause is in the basal center, the explanation would seem to be that the center is incapable of storing and discharging the proper quantity of neuricity.

As has been shown already, the basal centers are perfectly at rest in every correct test for heterophoria, for the reason that, in making such a test, the false image has been thrown entirely beyond the limits of the field of fusion. The fusion faculty of the mind, under such a condition, is wholly unable to excite into activity a single basal center. *The basal centers never enter into the causation of heterophoria, but stand ready always to respond to the demands*

of the fusion faculty of the mind, for correcting heterophoric conditions.

Prism test for duction.—This test should be applied to only one eye at a time. The head should be erect and the test object should be at 20 feet or more distant, and practically in the line of intersection of the extended median and horizontal fixed planes of the head. The object should be either a small light or a white dot on a blackboard. One of two methods of using the prisms may be adopted. The first, but not the best, is to place a weak prism before the eye and then successively place stronger prisms until the muscle under test can no longer fuse the image in its eye with the image in the other eye, the test object now being seen as two objects. It must be remembered that the apex of the prism points towards the muscle whose duction power is being taken, and that the image is displaced towards the base of the prism.

Abduction.—In testing abduction the base of the prism must be towards the nose while the apex points towards the temple. The axis of the prism must lie in the horizontal plane of the head. Placing a 1° prism thus, the externus immediately moves the macula under the displaced image and vision becomes single. The same thing is true, but not quite so rapidly, when 2°, 3°, 4°, 5°, 6°, 7° and 8° prisms are so placed, the externus being possessed of normal duction power. If the tonicity test has shown lat-

eral orthophoria, and abduction is 8° or more, the condition is sthenic orthophoria; but the condition is asthenic orthophoria if abduction is much less than 6° or 8°. If the tonicity test reveals exophoria, an abduction of more than 8° shows that the externus is intrinsically too strong, but an abduction of less than 8° shows that the externus is not intrinsically too strong. If the tonicity test reveals esophoria, an abduction of 8°, a little less or a little more, shows that the inherent power of the internus is too great, but if the abduction is much less than 8°, the indication is that the internus is not too strong intrinsically. The abduction test is valuable for the reason that it gives reliable information as to what muscle should be operated on in either exophoria or esophoria. It answers the question better than anything else can: "Should the too strong muscle be made weaker by a partial tenotomy, or should the weaker muscle be made stronger by a shortening or advancement?"

The faculty of the mind that presides over all duction centers is the fusion faculty, and the center by means of which abduction is controlled is the fourth basal center. This center seems incapable of over-excitation, hence abduction can be increased only as muscle tone is increased by either exercise or by operation.

Adduction.—The test for adduction cannot be relied upon, for the reason that the third basal center which controls it is a very excitable and powerful center. This is shown by

the fact that adduction can be greatly increased although there has not been time nor effort for improving the tonicity of the internus. Normal adduction is stated by most authors to be about three times greater than abduction; but it is well known that adduction in some cases may be made to reach 50° or more, after a few trials. In some cases, however, adduction is very low, and repeated efforts fail to increase it much. In making the test for adduction, by prisms from the trial case, the base of each prism is toward the temple and expex points towards the nose, the axis of the prism lying in the horizontal plane of the head. Beginning with a 5° prism, the strength is increased by 5° with every change, until the internus no longer receives a fusion impulse, the false image having been thrown templeward entirely outside the retinal fusion area.

Subduction.—To test the duction power of the inferior rectus, by prisms from the trial case, a ½° prism is placed apex down and is so held that its axis is parallel with the median plane of the head. With every change of prisms there should be an increase of ½°, until that prism has been placed which cannot be overcome by the muscle, for the reason that it receives no impulse from its second basal center, the false image having been thrown entirely beyond the upper boundary of the retinal area over which the fusion faculty has control. The strength of the last prism that the muscle could overcome is the measure of its duction

power. This is placed, by most authors, at 3°, but it is oftener less than more.

Superduction.—The duction power of the superior rectus is taken precisely in the same manner as set forth in the paragraph on subduction, with the exception that each prism must be held with its apex up. Under the stimulus of its basal center (the first) the superior rectus, with normal tonicity, should overcome a prism of 3°. Rarely is its duction power more, while very often it is less than 3°. If the eye under test is hyperphoric superduction may be considerably more than 3°. Whatever may be the quantity of hyperphoria, the superior rectus that cannot overcome a prism of more than 3° should not be weakened by a partial tenotomy. An operation on a superior rectus should never reduce its duction power below 3°.

In taking the duction power of any muscle by means of the prisms in the trial case, only one eye should be tested at a time. The image in the eye not under test should be constantly on the macula, and both the head and the eye should be in their primary positions. So long as the image in this eye remains unmoved, no neuricity will be sent to any one of its six muscles, from either their cortical or basal centers. When the prism is held before the eye whose muscle is to be tested, the image of the test object is thrown from the macula in the direction of the base of the prism. If it falls within the fusion area toward the nose, the fusion

faculty of the mind instantly discharges from the fourth basal center a quantity of neuricity that will make the externus move the eye, at once and quickly, so as to bring the macula under the displaced image. If the image falls beyond the nasal border of the fusion field, no neuricity is sent from the fourth basal center to the externus and the eye remains still, provided there is no lateral heterophoria. If there is a lateral heterophoria the eye, no longer influenced by the fusion faculty, assumes its position of rest, or that position into which the tonicity of all the muscles would place it.

If the displaced image falls on the fusion area, the direction in which it has been thrown determines which basal center shall be discharged by the touch of the fusion faculty, and which muscle shall be made to lead the macula under the false image: nasal-ward, the fourth basal center and the externus; temple-ward, the third basal center and the internus; below, the first basal center and the superior rectus; above, the second basal center and the inferior rectus. In either case the discharge is sudden, full and sufficiently powerful to effect a quick rotation, that there may be no prolonged diplopia.

Rotary Prism.—The easiest and best means for determining the duction power of any rectus muscles is the rotary prism of the monocular phorometer. With this instrument the image is not thrown, but is made to glide, in a definite

direction, but at no time is the image allowed to leave the macula, until the duction power of the muscle has been surpassed. Diplopia does not occur so long as the macula is kept under the moving image. The moment the fusion faculty allows the basal center involved to cease discharging neuricity to the muscle whose gradually increasing contraction has kept the macula under the moving image, that moment diplopia occurs, the false object moving rapidly from the true. The fusion task having been abandoned, the eye assumes the position of tonicity of all its muscles; and the image rests beyond the border of the fusion area until the prism is rotated backward towards the neutral position. Only 10° of duction can be measured by the unaided rotary prism, but this is more than sufficient for determining sub- and superduction and abduction, when there is orthophoria. In taking adduction the 15° supplementary prism must be placed base out behind the rotary prism, 10° of the power being neutralized by placing the index of the rotary prism at the 10° abduction mark. Thus, beginning with 5° displacement of the image temple-ward, which is easily overcome by the internus, the rotary prism is revolved back through the abduction arc into the adduction arc. After passing the zero mark, every degree of rotation adds to the full effect of the 15° prism, and when the full adduction arc has been traversed by the index of the rotary prism, the combined effect is 25°. If diplopia has not yet occurred

adduction is more than 25°; if it occurs while the rotary prism is on its way to the 10° adduction mark, the position of the index is noted, and if it stands at 8°, at the moment of diplopia, adduction is 23° (15°+8°). To find higher adduction than 25°, the 10° supplemental prism must be placed base out, in front of the rotary prism, while the 15° prism remains in the cell behind it. The two supplemental prisms have a combined displacing power of 25°, but 10° of this power should be neutralized, at the beginning, by placing the index of the rotary prism at 10° in the abduction arc. The remaining 15° is easily overcome by a very strong internus. When the rotary prism has been revolved until its index stands at zero, the adduction, up to this point, is 25°; as the index moves in the adduction arc, every degree of advance adds that much to the 25° of the two supplementary prisms. If diplopia occurs when the index points to 8°, the adduction is 33° (25°+8°). Higher adduction than 35° cannot be taken easily with the monocular phorometer. Ordinarily a normal discharge of neuricity from the third basal center to an internus, even when there is esophoria, does not produce more than 35° adduction.

When abduction is more than 10°, which is often the case in exophoria, the rotary prism must be aided by the 10° supplementary prism. This should be placed base towards the nose, in the cell behind the rotary prism, and its power,

at first, should be neutralized by placing the index of the rotary prism at 10° in the adduction arc. Moving the index to zero, the full power of the supplemental prism is made manifest; carrying the index into the abduction arc, the displacemnt of the image nasal-ward is increased, and the externus must contract still more, to keep the macula under the moving image. The moment diplopia occurs the rotary prism must be stopped. If now the index stands at 5°, the abduction is 15° (10°+5°); if the index stands at 10°, abduction is 20° (10°+10°). Cases of exophoria are rare in which abduction is greater than 20°, but when it is, then the 15° supplemental prism should replace the 10° prism.

The value of the duction test is great, whether made with prisms from the test case or by means of the rotary prism. Its value is greatly lessened if the head is not in the primary position, and if one eye is not allowed to remain in the primary position throughout every test. The sole object of the test is to determine the influence that the fusion faculty of the mind has over *one* basal center to excite the contractile power of *one* muscle, in the interest of binocular single vision. To accomplish this there must be no displacing prism before one eye; and the axis of the displacing prism before the other eye must point in one of the four cardinal directions.

The author recognizes the fact that, in sub- and super-

duction, two centers are excited, one of these controlling a rectus muscle and the other an oblique muscle; but for practical purposes this double excitation should be ignored, only the rectus muscle and its center being kept in mind.

Whenever the axis of the displacing, or duction, prism is held obliquely, two recti muscles and their centers are excited into activity.

Low duction in orthophoria indicates ceiling-to-floor and wall-to-wall exercise; high duction power in orthophoria indicates that there is nothing to be done to the recti. Low abduction in exophoria contra-indicates a partial tenotomy of the externus, and indicates a shortening of the internus; high abduction in exophoria indicates a partial tenotomy of the externus and contra-indicates a shortening of the internus. In esophoria adduction cannot be depended on so certainly as can abduction, in the effort to determine on what muscle an operation should be done and the character of the operation. Very low abduction in esophoria would indicate a shortening of the externus; abduction approximating 8° would indicate a partial tenotomy of the internus. The version test can be relied on in determining the muscle to be operated upon, but not so implicitly as can the duction test. Only the tonicity test of the obliques can determine whether a tenotomy of a rectus muscle should be central or marginal, and whether a shortening or advancement should be so done as to change the rotation plane of the muscle.

Why muscles with equal tonicity should not have equal duction power seems susceptible of only one explanation, viz.: the muscle that has the greater duction power, as the internus, has the more powerful basal center; and the muscle that has the weaker duction power, as the externus, has a weaker basal center. Difference in the quantity of neuricity sent by a basal center to a muscle determines the difference in duction power, in orthophoric cases. This is made more apparent by recalling the fact that, in lateral orthophoria, abversion is equal to adversion, to effect which neuricity, from a common source, is sent in equal quantities to the externus of one eye and the internus of the other.

Cyclo-duction.—The duction power of an oblique muscle (cyclo-duction) can be taken with the clinoscope. The translucent discs, with lines entirely across, must be used, and they must be so placed that both lines shall be either vertical or horizontal. With the tubes properly adjusted the two lines would be seen as one. Revolving one tube would displace one line, which would cause a corresponding change in position of the retinal image of that line. To prevent diplopia the fusion faculty of the mind calls into action the basal center that controls the action of an oblique, thus torsioning the eye so that the image, though changed in position, shall still lie on the original meridian.

It is well known that there is a greater disposition on the part of the mind to fuse horizontal lines than there is to fuse

vertical lines. The only explanation for this is that the fusional retinal area is many times longer (horizontally) than it is wide (vertically), so that the image of the horizontal line would lie almost, if not entirely, in the fusional area, while a good part of the image of a vertical line would fall on retinal surface outside the fusional area. In the former case the fusion stimulus would be greater than in the latter. For this reason the test lines should be placed horizontally in the clinoscope. Thus placed, if the one tube is revolved so as to make its line dip toward the opposite side, the superior oblique of the corresponding eye is excited into action by its proper basal center (the sixth), under the guidance of the fusion faculty of the mind. The revolving of the tube is continued until the lines begin to double. The index shows the extent of the revolution of the tube, and the degree of the torsion accomplished by the superior oblique (minus cyclo-duction), in the effort to keep the image in its eye fused with the image in the fellow eye.

To test the fusion power of the inferior oblique (plus cyclo-duction), one tube must be revolved so as to make the line dip towards the corresponding side. Minus cyclo-duction and plus cyclo-duction are practically equal, and each, with the clinoscope, may be as much as 14°, but it is more often less.

The cyclophorometer is easier to adjust than the clinoscope, and is just as accurate in determining cyclo-duction.

It is made on the principle that the test lines (streaks of light) should always be horizontal. At first the instrument should be arranged as in testing for cyclophoria; that is, the triple rods should be placed in their cells with axes vertical, each index pointing to zero. A displacing prism should be placed, base up, behind one triple rod. The room should be darkened and the test object should be a candle blaze, or, better still, a bright point of light. With the instrument properly leveled, two horizontal streaks of light should be seen, and their ends should be made even by means of the adjustment screw. On removing the displacing prism the two streaks are at once fused. To test the fusion power of a superior oblique (minus cyclo-duction), the rod before the eye under the test should be revolved in the lower temporal arc until the line of light begins to double. The index will show the degrees of displacement of the image, and the amount of torsion that has been effected to prevent diplopia.

To test the fusion power of an inferior oblique (plus cyclo-duction), the triple rod before the eye under test should be revolved in the lower nasal arc until the line of light begins to double. The index points to the number of degrees of torsion that has been effected in the interest of fusion.

The instrument for testing cyclo-duction must necessarily be a binocular instrument; but it is important that only one muscle of one eye shall be under test at one and the same time.

CHAPTER II.

THE BRAIN CENTERS CONTROLLING THE OCULAR MUSCLES.

The following study of the action of the ocular muscles, from the brain side of the question, is based on pathology and physiology, and not on anatomy and histology. Experimentation on the lower animals has shown that irritation at a certain point of the motor area of the left cortex will cause both eyes to turn to the right, spasmodically, and that destruction of this part of the cortex will cause both eyes to turn paralitically in the other direction. Irritative and destructive disease of the cortex, in human beings, have shown the same thing.

There seems no good reason for doubting the existence of conjugate cortical brain centers for the control of the ocular muscles, notwithstanding the fact that the scalpel and the microscope can never trace the two fibers, or two sets of fibrils, from the one common brain center to the two muscles (one belonging to each eye) under its control.

Maddox, in his admirable work, "The Ocular Muscles," says: "The number of conjugate innervations is, at present,

unknown. Five have long been recognized; of which one elevates both eyes, another depresses them, a third turns both to the right, and a fourth both to the left. The fifth is the convergence innervation." Continuing, he says: "Besides these five, I imagine there may be three which govern torsion, and two which regulate the vertical balance of the eyes."

In his former work, "*Ophthalmic Myology*," the author taught that there are nine conjugate innervation centers for the control of the twelve extrinsic ocular muscles; that five of these centers are connected with the eight recti muscles, each center with two muscles, one of which belongs to the right eye, the other belonging to the left eye; that four of the nine centers are connected with the four oblique muscles, each center with two muscles, one belonging to the right eye, the other to the left eye. During the three years that have intervened, the author has not had cause for changing his mind as to the existence of these nine conjugate brain centers; but his views as to the exact character of work done by these centers have been changed somewhat, as the result of further study. More than two years ago the author recognized the fact that the conjugate brain centers could make the muscles obey the law of binocular rotations, only when the muscles of each pair are perfectly balanced—when there is orthophoria. The explanation that the upward rotation could be accomplished without di-

plopia, when one eye is hyperphoric and the other cataphoric, by an unequal discharge of neuricity from the first conjugate center to the two superior recti, the greater quantity going to the weaker muscle, was not satisfactory. It seems more reasonable to suppose that when a conjugate center discharges its stored neuricity, it is equally divided between the two muscles. To make the weaker muscle rotate its eye in perfect harmony with the eye having the stronger muscle, there must come to the former, from some other source, a supplemental quantity of nerve-force. Whence this added force and what mind-power controls it? The answer was first given at the meeting of the Section of Ophthalmology of the American Medical Association, in New Orleans, in 1903, by the author, in a paper entitled, "The Voluntary and Involuntary Brain Centers Controlling the Ocular Muscles." The following quotation is from that paper:

"There is one basal center for each ocular muscle, and each center can act on only one muscle. The basal centers are all under the control of the fusion faculty of the mind, and none of them are ever called on to discharge neuricity unless a condition exists that would cause diplopia."

The power that can cause harmonious upward rotation when one eye is hyperphoric and the other is cataphoric must come from two sources. Volition unlocks the

first conjugate center, which sends an equal quantity of neuricity to the two superior recti; the fusion faculty of the mind unlocks the first basal center. connected with the weaker muscle, which sends to it a supplemental quantity of neuricity, making its eye move as fast and as far as its fellow, thus preventing diplopia.

The conjugate centers are all in the cortex, probably in the anterior part of the motor area. Future observers will locate these centers accurately. There are nine in connection with the recti and oblique muscles, one connected with the ciliary muscle, and one with the sphincter muscle of the iris. There must also be a conjugate cortical center for the two muscles that elevate the upper lids. Fibers from the latter center help to compose the third nerve; but in the plate illustrating the third nerve, these fibers, and the center from which they come, will not be included, nor will the elevator muscles be figured.

The conjugate centers, probably, are not widely separated in the cortex, but their exact arrangement in the group is unknown. In the illustrative plates to follow, all these centers are represented schematically, and they are numbered arbitrarily. Those connected with the recti muscles are numbered from 1 to 5, and those connected with the obliques are numbered from 6 to 9. The tenth is the one connected with the Muller muscle of the ciliary body. The eleventh is connected with the sphincter muscle of the iris.

From each cortical conjugate center go two fibers, or two sets of fibrils; one goes to a single muscle on the corresponding side, the other crossing the median line goes to a single muscle on the opposite side. These muscles thus united with a common center, constitute a pair. Evidently the centers formed in the cortex of one hemisphere exist in duplicate in the other hemisphere, and each duplicate center must have a connection with the same two muscles. To illustrate, the first conjugate center in the left cortex is connected with the two superior recti and supplies them with power. The first conjugate center in the right cortex must have a similar connection with the two superior recti, but this center sends no neuricity to these muscles, and therefore does not excite them into contractility.

Two centers, one on each side of the brain, connected with each pair of muscles, and only one of these centers active, may be always a subject for disputation. It is reasonable to suppose that, at the time of birth, one of these centers stands as ready to effect a given rotation as does the other. Why one should become active and the other remain inactive, throughout life, must be determined by some pre-existing condition, and not by chance. It is not enough to say that in right-handed people the left brain dominates, and in left-handed people the right brain dominates: for the condition that makes the left brain or the right brain dominant, also makes the person right-handed

or left-handed. The author has taught, for many years, that the predetermining condition is the connection that the maculas have with the brain. If all the fibers from the two maculas meet in the left tract, they must go together to the left cuneus; but if they all meet in the right tract, they must go to the right cuneus. In the former condition, direct vision would excite only the left cuneus; in the latter, direct vision would excite only the right cuneus. The transmission of all macular impressions to the left cuneus establishes, it is reasonable to suppose, the dominancy of the left hemisphere, especially as to those cortical centers that largely depend for their development on vision. Even the speech center, either directly or indirectly, becomes fixed on the same side. The same should be said of the right hemisphere, when all macular impressions are conveyed to the right cuneus.

The hand and arm centers exist in both hemispheres, and both are developed, usually one more highly than the other; but the centers in the left brain are connected with the right arm only, while those in the right brain are connected with the left arm only. The right and left hands never act as one organ.

The respiratory muscles exist on both sides of the body and act not only in harmony, but simultaneously, as if they constituted a single organ. The centers in the left hemisphere and the centers in the right hemisphere, each must

be connected with two respiratory muscles, one on either side of the body; and each of these muscles must receive a double impulse, one from its center in the right brain, and one from its center in the left brain. This is made evident by the fact that, while disease or injury of one side of the brain will weaken the action of the muscles of respiration on both sides, it will not paralyze them on one side and leave them active on the other side. Like the centers controlling the extremities, the centers of respiration in both sides of the brain are active; but unlike the centers controlling the extremities, the centers of respiration in each side have connection with muscles on both sides of the chest. The muscles of the chest are like those of the eye in that each is connected with two centers, one in either hemisphere; but while the former are acted on by both centers, the latter receive neuricity from centers on only one side of the brain.

In the illustrative plates to be studied, all the active conjugate cortical centers, except the fifth, are situated in the left hemisphere, and all the non-acting centers, except the fifth, are placed in the right hemisphere. The active centers are represented by larger circles, and the non-active by smaller circles. The conjugate centers known to be under the control of volition are each crossed by two parallel lines. The sixth and seventh conjugate centers exist solely in the interest of binocular single vision, and are sup-

posed to be under the control of the fusion faculty of the mind. The circles representing these are not crossed by parallel lines.

The basal centers connected with the twelve extrinsic ocular muscles all exist in the interest of binocular single vision, each is connected with only one muscle, and they are all under the control of the fusion faculty of the mind. Unless some condition exists or arises that would cause diplopia, these centers are ever inactive, their normal state being one of rest. Their location is on either side of the median line beneath the aqueduct of Sylvius and in the anterior part of the floor of the fourth vertical. In the plates to follow, the basal centers are represented schematically, and they are numbered in harmony with the numbering of the conjugate cortical centers. They exist in pairs, but work independently. They all stand ready always to discharge neuricity that images may be fused, but a discharge from a single center can affect only a single muscle.

There are doubtless basal centers for Muller muscles of the ciliary body and for the sphincter muscles of the iris, and these are represented in each plate. The former are right and left tenth basal centers, and the latter are right and left eleventh basal centers. In emmetropia, and in ametropia, the error being equal in the two eyes, the tenth basal centers would have nothing to do. When there is unequal refraction the muscle that must exert the greater

power for the formation of a sharp image must receive supplemental neuricity from its basal center; for the tenth conjugate center, like the conjugate centers that control the extrinsic muscles, sends neuricity in equal quantities to the two ciliary muscles, equal contraction resulting. Again, the necessity for the tenth basal centers may be understood by conceding the possibility that the ciliary muscles may be endowed with unequal tonicity. When this is true the tenth conjugate center cannot excite equal contraction, and supplemental neuricity must come from the basal center connected with the weaker muscle.

The right and left eleventh basal centers are shown in the plates, as is also the eleventh conjugate center. These centers are connected with the sphincter muscles of the iris. If the sphincters are of equal tonicity the conjugate center alone will act; but if they differ in tonicity, the muscle that is weaker must have supplemental neuricity from its basal center.

The extrinsic and intrinsic muscles of the eye have their connection with the conjugate and basal centers through the medium of three pairs of nerves—the third, the fourth and the sixth cranial nerves. Plate I. represents the connection of brain centers and muscles through the medium of the right third nerve. A study of this plate will show that the third nerve is nothing more nor less than a cable composed of many insulated nerve fibers, which connect

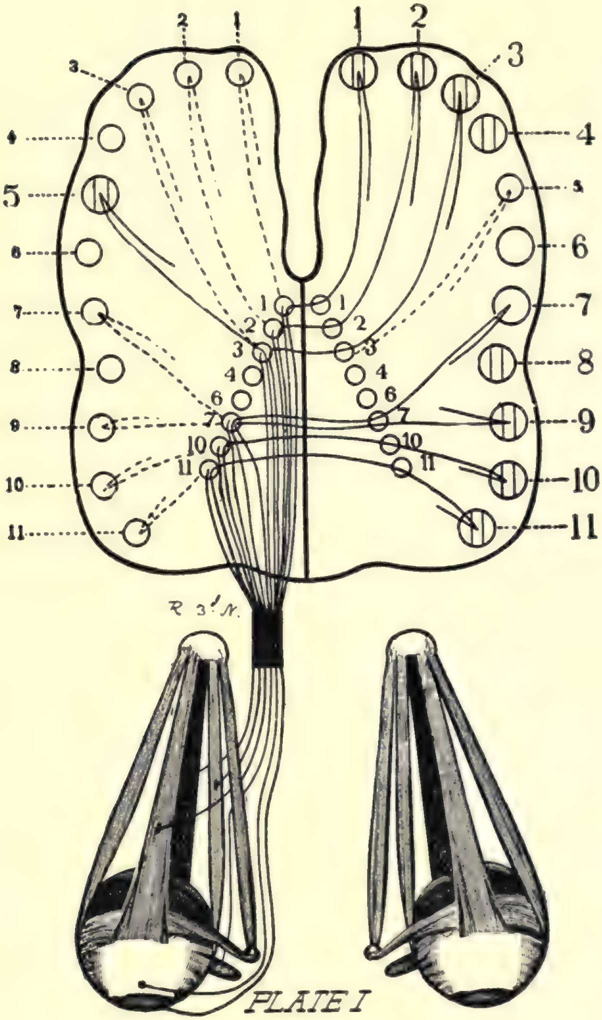


PLATE I

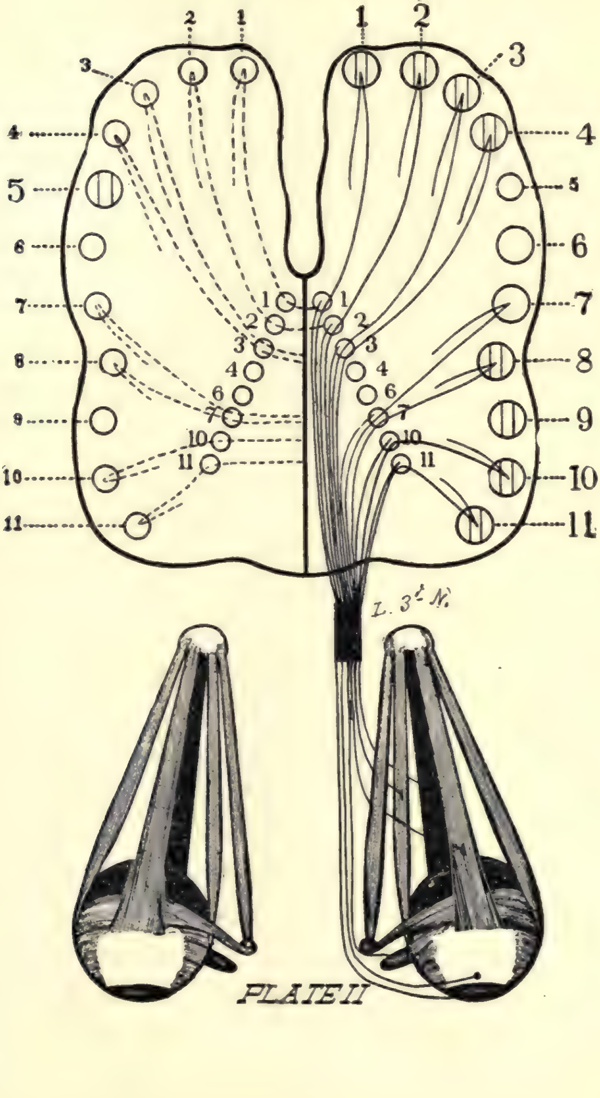


PLATE II

eight active conjugate centers and six basal centers with three recti muscles, one oblique muscle, the ciliary muscle and the sphincter of the iris. The left side of that part of the plate representing the brain is the dominant hemisphere. From each conjugate center two lines are drawn, one stopping in mid-brain, the other extending on, by way of the basal centers, to help form the third nerve cable. The line stopping midway between conjugate and basal centers represents the fiber, or set of fibrils, that would help to form the left third nerve, which is shown in Plate II.

The first conjugate center, which controls the two superior recti, sends a fiber, or set of fibrils, to the left first basal center, thence across to the right first basal center, thence on in the sheath of the right third nerve to the right superior rectus. In the right first basal center begins a neuron whose insulated axone passes within the third nerve to the right superior rectus. Over the former line travels the volitional impulse; over the latter travels the fusion impulse.

The second conjugate center, which controls the two inferior recti, has two fibers, or sets of fibrils, one to reach its destination through the right third nerve and the other through the left third nerve. The former passes to the left second basal center, thence across to the right second basal center and thence in the right third nerve to the right inferior rectus. The right second basal center sends its con-

necting line, in the third nerve cable, to the right inferior rectus.

The third conjugate center, or the convergence center, is connected with both interni. The fiber, or set of fibrils, to connect with the right internus, passes down to the left third basal center, thence across to the right third basal center, thence to help from the body of the right third nerve, on to its destination in the right internus. The right third basal center sends a connecting line through the right third nerve to the right internus.

The fifth conjugate center in the right hemisphere is connected with the right internus through the right third nerve and with the left externus through the left sixth nerve. The former connection is shown in Plate I. and the latter is shown in Plate VI.

The seventh conjugate center is connected with both inferior obliques. The connection with the right inferior oblique is by way of the left seventh basal center, across to right seventh basal center, thence on in the body of the right third nerve to the right inferior oblique. The right seventh basal center has its independent connection with the same muscle, by way of the same nerve.

The ninth conjugate center is connected with the right inferior oblique and the left superior oblique, the former being shown in Plate I. and the latter in Plate IV.

The tenth conjugate center is connected with the Muller

muscle of accommodation in each eye. Its connection with the right eye is by way of the left tenth basal center, across to the right tenth basal center, thence on, through the right third nerve to its destination. The right tenth basal center has its connecting fibers passing down in the right third nerve to the Muller muscle of the right eye.

The eleventh conjugate center is connected by means of the right and left third nerves with the sphincter muscles of the iris of both the right and left eyes, the right connection being shown in Plate I. and the left connection being shown in Plate II. The basal center connections are likewise shown in the two plates.

A glance at Plate I. will show that the third nerve cable is composed of insulated fibers from eight of the eleven active conjugate cortical centers; that the fibers from seven of these centers cross the median line to help form the right third nerve, the only non-crossing fibers coming from the fifth conjugate center. The broken lines from the corresponding eight inactive centers are intended to show a connection between these centers and the muscles controlled by the eight active centers.

Plate I. also shows that the right third nerve has in it insulated fibers from six of the eight right basal centers. None of these basal fibers have crossed.

Plate I. is not a complete picture of the brain and muscle connections composing the right third nerve. In each third

nerve there are fibers from a conjugate center controlling the elevator muscles of the upper lids. There are also fibers in each third nerve from the superior cervical sympathetic ganglion. Some of the fibers from this ganglion are probably distributed to the Bowman fibers of the ciliary muscle and others to the radiating fibers of the iris. The impulse sent over the former fibers, in all probability, causes a tilting of the lens for correcting a corneal astigmatism.

No attempt is made in Plates I. and II. to show the ciliary ganglion through which pass all the short ciliary fibers of the third nerve on their way to the muscles in the ciliary body and in the iris.

Plate II. shows that the left third nerve cable is composed of fibers from eight active conjugate centers, all in the left hemisphere and from six basal centers, also in the left hemisphere. The fifth and ninth conjugate centers, which send axones through the right third nerve, have none in the left third nerve, the fourth and eighth conjugate centers taking their places. Only the left basal centers send axones into the left third nerve. All of the non-active conjugate centers, except the fifth, sixth and ninth, doubtless have axones in the left third nerve. None of the "live" fibers constituting the left third nerve cable are connected with the centers in the right hemisphere, hence there has been no crossing. This is in marked contrast with the fibers forming the right third nerve. This arrangement of

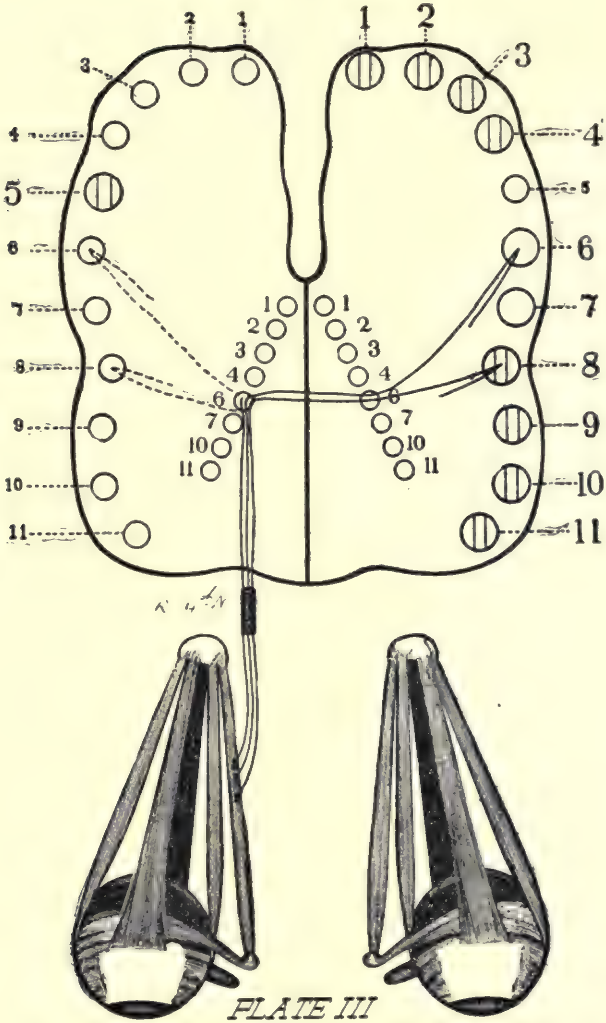


PLATE III

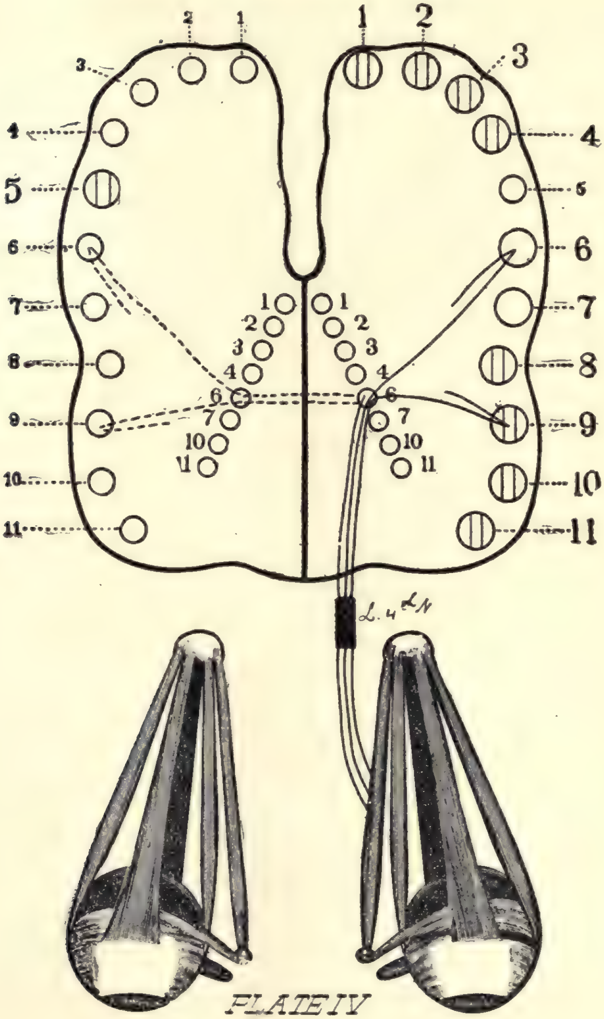


PLATE IV

fibers would be reversed in a person whose right brain is dominant—in a person whose maculas are wholly connected with the right cuneus.

Of the eight conjugate centers that send fibers through the third nerve cables to the superior, inferior and internal recti and to the inferior oblique, not more than three are ever active at the same time, and in some of the binocular rotations all these centers except one will be in a state of rest. But this will be clearly shown in subsequent plates.

THE FOURTH PAIR OF NERVES.

Plate III. shows the conjugate and basal centers whose axones form the right fourth nerve, which is also a cable. The sixth conjugate center sends fibers to both superior obliques. The fiber, or set of fibrils, destined for the left superior oblique, are carried in the plate only part of the way to the sixth basal center, but the fiber to connect with the right superior oblique is carried down to the left sixth basal center, thence across to the right sixth center, thence on in the right fourth nerve to its termination in the superior oblique. Starting in the right sixth basal center is an axone that helps to form the right fourth nerve, finally ending in the right superior oblique.

From the eighth conjugate center goes a fiber, or set of fibrils, down to the left sixth basal center, thence across to the right sixth basal center, thence in the right fourth

nerve to the right superior oblique. The other fiber from this center, as shown in Plate II., helps to form the left third nerve, and ends in the left inferior oblique.

Plate IV. shows the conjugate and basal centers whose axones form the left fourth nerve. The conjugate centers are the sixth and ninth, and the basal center is the left sixth. There are no "live" crossed fibers in the left fourth nerve.

THE SIXTH PAIR OF NERVES.

Plate V shows that the fourth conjugate center and the right fourth basal center have "live" axones in the right sixth nerve, which, too, is a cable. The silent fourth conjugate center sends axones, as shown by the broken line, to the right fourth basal center, thence in the right sixth nerve to the right externus. The fiber represented by the broken line conveys no neuricity, for its center discharges none. The right externus has only two sources of neuricity, the fourth conjugate center and the right fourth basal center. The former center is active only in the right sweep of the eye, and the latter is active only in the interest of binocular single vision.

Plate VI. shows that axones from the fifth conjugate center and from the left fourth basal center form the left sixth nerve. The former is active only in the left sweep of the eye, and the latter acts only in the interest of binocular single vision.

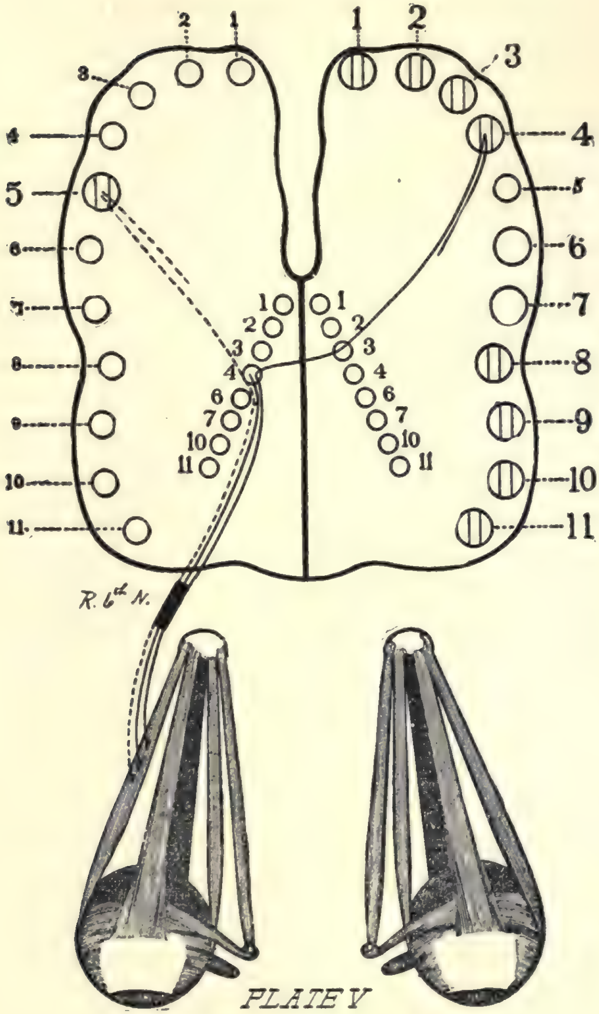


PLATE V

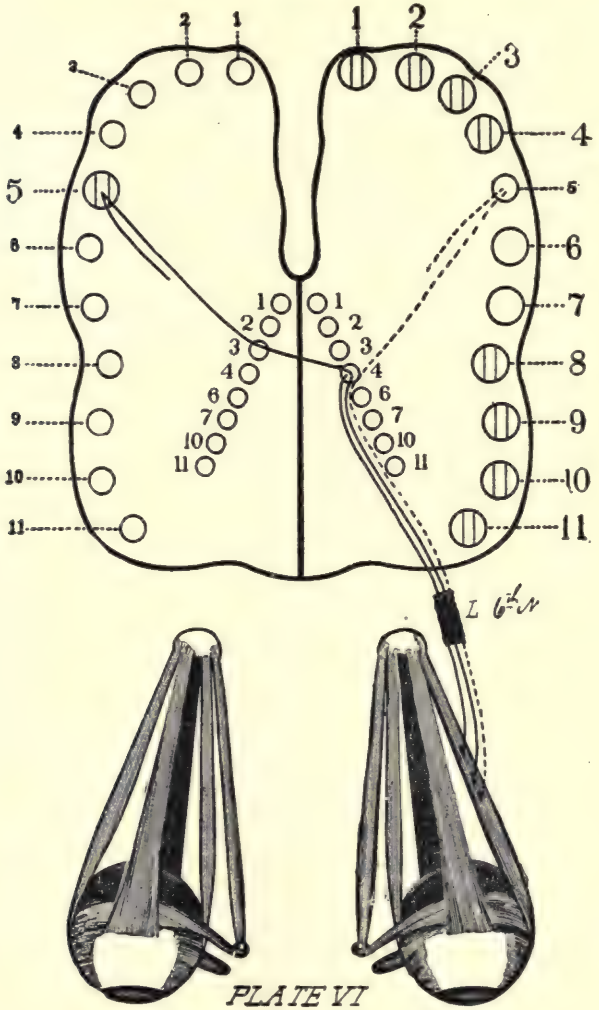


PLATE VI

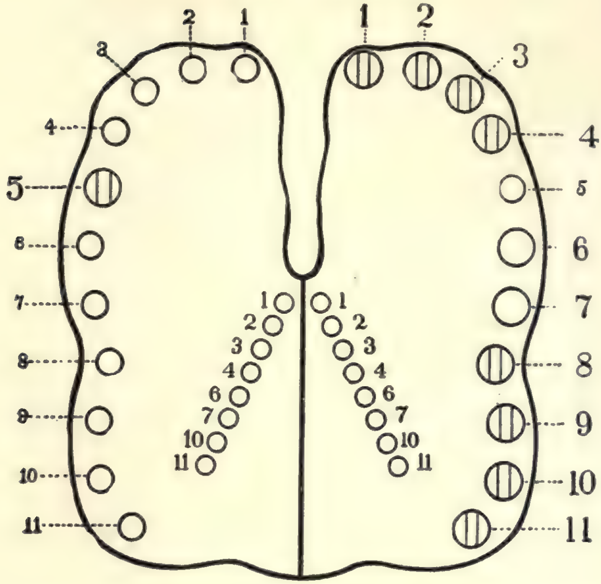
EMMETROPIA—ORTHOPHORIA.

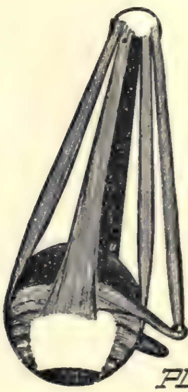
Plates VII. to XVI. inclusive are intended to show that in emmetropic-orthophoric eyes, regardless of the point of view, no basal center is ever called on to discharge neuricity. These plates likewise show that, in such cases, restfulness is the normal state of all the basal centers.

Plate VII. represents the restfulness of all brain centers, the conjugate and the basal, and the consequent restful state of all the eye muscles, extrinsic and intrinsic, when the head is in the primary position and the emmetropic-orthophoric eyes are fixed on an object at practical infinity and in the line of intersection of the extended median and horizontal fixed planes of the head. This restfulness of brain centers and muscles could not be better represented than by leaving out their axonic connections. If a brain center is not discharging neuricity, the muscle is not contracting, and the axone is not alive. The condition is as if the axone were absent.

From this restful state of brain and muscle, the eyes may be moved, or rotated, instantly into any of the positions represented in Plates VIII. to XVI., as a result of the action of volition on the respective conjugate brain centers, the basal brain centers remaining inactive. Each of these plates represents the eyes ready to begin the respective rotations, and not the completed act.

Plate VIII. represents the act of convergence of emmetropic-orthophoric eyes, the associated action of the accommodation, and the brain centers that have effected these changes from the restful state shown in Plate VII. The head is still in the primary position, and the near object is in the line of intersection of the extended median and horizontal planes. Volition discharges the third conjugate center and causes a flow of an equal quantity of neuricity to each of the two interni, which, responding with equal power, converge the visual axes to the point of fixation. Simultaneously, volition unlocks the tenth conjugate center, which sends an equal quantity of neuricity to each of the Muller muscles of accommodation, thus causing a perfect focusing, on each retina, of the rays of light coming from the point of fixation. The whole work of changing the eyes from the restful state shown in Plate VII. to the state of convergence-accommodation activity, has been accomplished by the internal recti, under the influence of the third conjugate center, and by the Muller muscles under the influence of the tenth conjugate center. The activity of the muscles, and of the centers exciting them, is shown by the lines drawn from the two conjugate centers through the proper basal centers to the muscles. The absence of lines extending from other conjugate centers to other muscles is intended to show the restful state of both. The absence of axones extending from right and left third and the right and left tenth





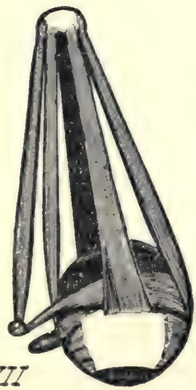


PLATE VII

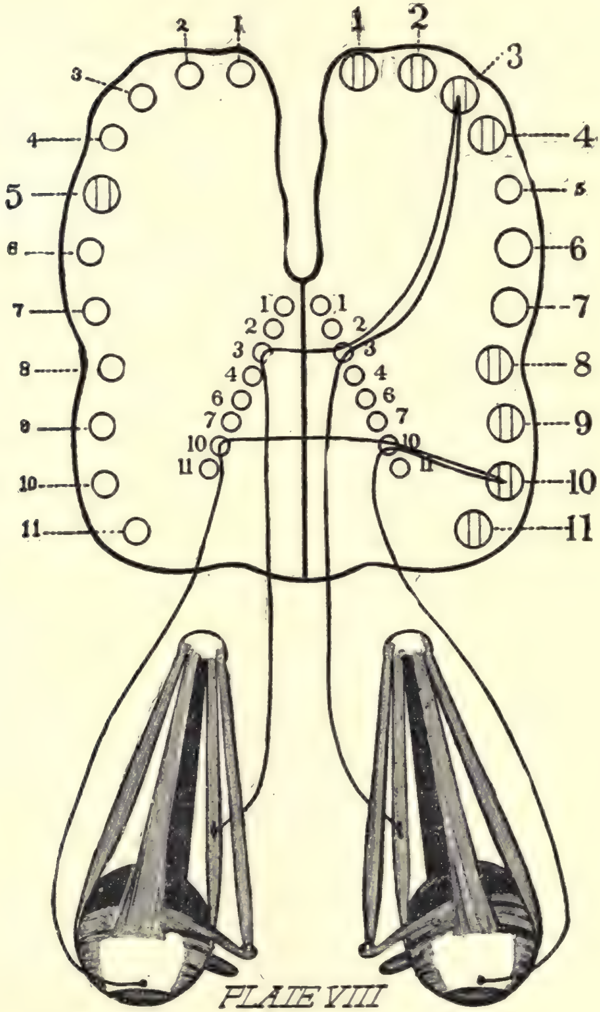


PLATE VIII

basal centers, shows that these centers are not concerned in the act of convergence-accommodation of emmetropic-orthophoric eyes.

To avoid confusion, no lines have been drawn from the eleventh conjugate center to the sphincter muscles of the iris, but it must be stated that, in accommodation, the pupils are always made smaller because of a discharge of neuricity from this center to its proper muscles.

The third and the tenth conjugate centers are most intimately related, in action, and this relationship is probably co-extensive with life. For every accommodative dioptre of neuricity discharged by the tenth conjugate center, a corresponding convergence dioptre of neuricity will be discharged by the third conjugate center. If the muscles supplied by these centers are normal in tonicity, there will be normal contraction from a normal stimulus.

It is a mistake to conclude that emmetropic and orthophoric eyes for distance can give no trouble in near seeing. Trouble may come from either one of two conditions of Muller's muscles: First, these muscles, in emmetropic eyes, may be wanting in tonicity; secondly, they may have an excess of tonicity. If wanting in tonicity they will require an excess of neuricity for the accomplishment of a given work. If the interni, in such a case, have normal tonicity, the right and left fourth basal centers will be excited into action whenever an accommodation-convergence effort is

made. Such a state is shown by esophoria in the near, when there is orthophoria for distance. This pseudo-esophoria is caused by the fact that the weak Muller muscles require four accommodative diopters of neuricity to effect a 3 D. change in the lenses; an associated four convergence dioptres of neuricity, sent to the normal interni, would cause an excess of convergence, to prevent which the right and left fourth basal centers would be excited by the fusion faculty of the mind. They would be made to discharge enough neuricty to their respective externi to counteract the excessive convergence. The excitation of these basal centers would be kept up only during accommodation-convergence. The centers acting in this condition are shown in Plate XVIII.

In the second place, when the Muller muscles have an excess of tonicity it may take only two accommodative dioptres of neuricity to effect a 3 D. change in the lenses. The associated two convergence dioptres of neuricity from the third conjugate center would not effect sufficient convergence, hence the right and left third basal centers, under the influence of the fusion faculty, must furnish supplemental neuricity to the normal interni. The centers excited in such a case are shown in Plate XXII. The excited right and left third basal centers become quiet the moment accommodation ceases, as is true of the right and left fourth basal centers when the Muller's muscles are lacking

in tonicity. Such eyes, though emmetropic and orthophoric, would cause trouble, but only when used in reading or other near work.

The pseudo-esophoria in the first case and the pseudo-exophoria in the second case, must be counteracted, and the effort made by the basal centers for this purpose, is doubtless, the source of the symptoms attending the near use of such eyes. The treatment of such cases should be directed towards the relief of the basal centers, whose normal state is rest, and not action. The pseudo-esophoria can be cured in one of two ways: First, by rhythmic exercise of the ciliary muscles, increasing their tonicity to the normal; second, by allowing the patient, though young, to wear convex lenses of proper strength for near work. Relief comes from either plan of treatment, but the former should be adopted. Likewise the pseudo-exophoria may be treated in one of two ways: First, exercise of the interni, by prisms, or by the candle method, so as to develop in them an excess of tonicity; second, by permitting the patient, though emmetropic, to wear concave lenses of suitable strength, in near work only. Either plan may bring relief, but the former should be adopted.

THE VERSIONS.

Plate IX. is intended to show the activity of brain and muscles in effecting the right sweep of the eyes—right ver-

sion. The rotation plane lies in the fixed horizontal plane of the head; the visual axes are practically parallel; the only active muscles in this rotation are the right externus and the left internus; and the center that controls them is the fourth conjugate. The lines extending from this center to these muscles represent the axones down which the neuricity travels, in equal quantities, to the two muscles that have equal tonicity. The basal centers and all other conjugate centers are perfectly quiet. The antagonism of the right internus and of the left externus is only the antagonism of tonicity.

Plate X. illustrates left version, which is effected by the left externus and the right internus under the influence of the fifth conjugate center, the visual axes being practically parallel. All other muscles and centers, both conjugate and basal, are inactive.

When the visual axes are converged as in reading, the right and left versions are effected by the fourth and fifth conjugate centers respectively; and the other conjugate centers simultaneously active are the third and tenth. A combination of Plates VIII. and IX. would show the active muscles and the excited centers in right version associated with convergence and accommodation. A combination of Plates VIII. and X. would show the active muscles and excited centers in the left sweep of convergent eyes. In reading, if the head is tilted forward so that the

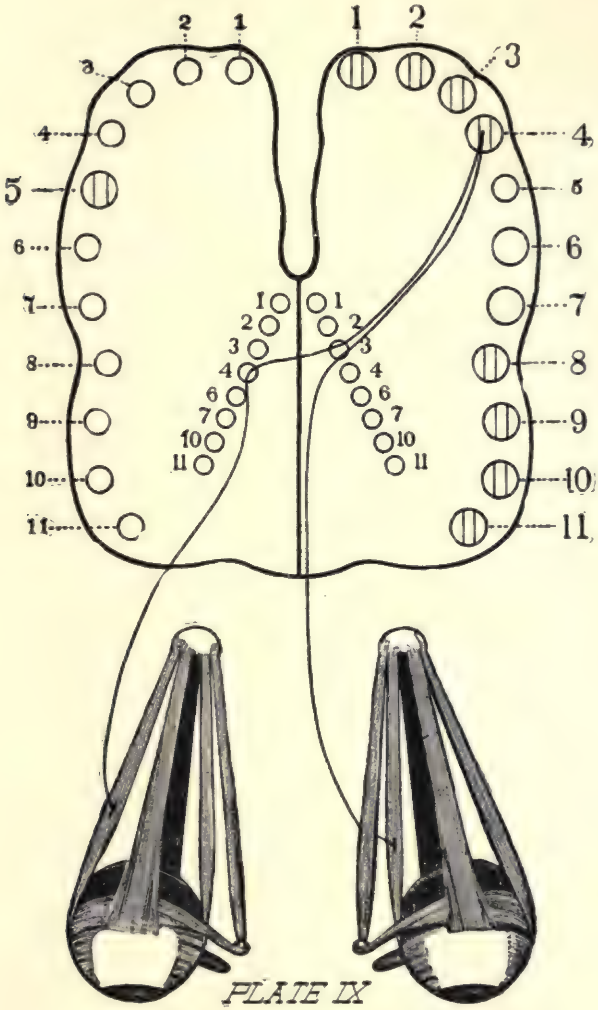


PLATE IX

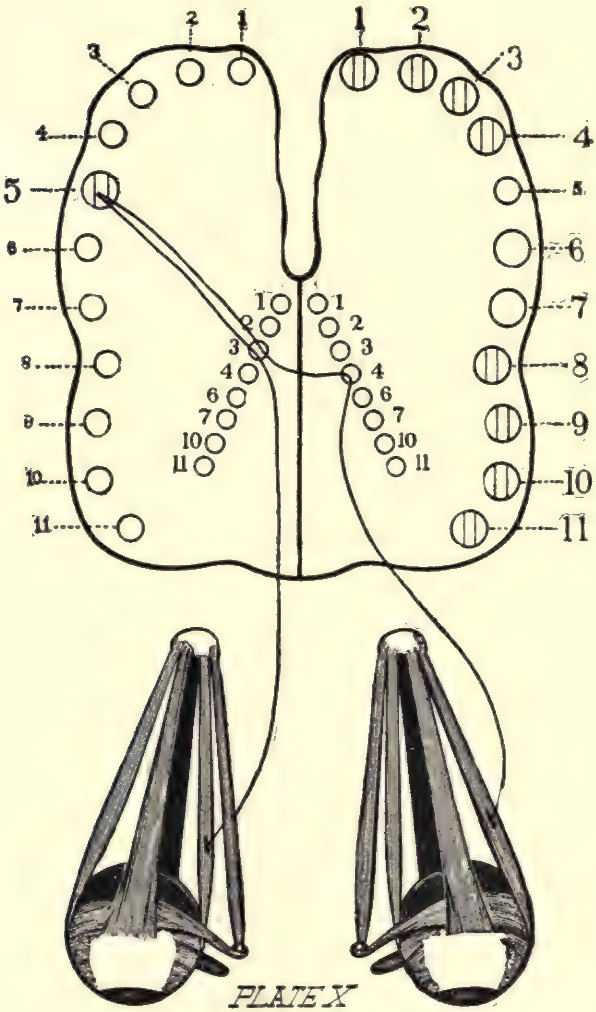


PLATE X

plane of rotation shall lie in the extended horizontal plane of the head, the muscles engaged are the two ciliary, the two interni, the right externus and the left internus, and the left externus and the right internus; and the centers controlling the action of these muscles are the third, fourth, fifth and tenth conjugate centers. If the plane of rotation falls below the extended horizontal plane of the head, as it must when one reads lying down, four additional muscles, the two inferior recti and the two superior obliques, must join in the work, and two additional conjugate centers, the second and the sixth, must become active. The natural pose of the head in reading or other near work is such as to cause a minimum excitation of the second and the sixth conjugate centers. There should be no reading in the recumbent posture, even when one is well and strong. The brain and muscle work expended when one reads while recumbent is shown by a combination of Plates VIII., IX., X. and XII.

The upward sweep of the eyes—superversion—is effected by four muscles, the two superior recti and the two inferior obliques. Plate XI. shows that this rotation of orthophoric eyes is effected by the first and seventh conjugate centers, and that all other centers, both conjugate and basal, are at rest.

Plate XII. shows that subversion is effected by the two inferior recti and the superior obliques under the control

of the second and sixth conjugate centers respectively, and that, in vertical orthophoria, all other centers are quiet. No error of refraction has any influence over the superior or inferior recti, or the conjugate or basal centers controlling them.

Plate XIII. shows the conjugate brain centers and the muscles that are concerned in the rotations up and to the right, the visual axes being parallel. The visual axis of the right eye is carried up and to the right in a plane common to the first and second points of view and the center of rotation, by the externus and superior rectus; and the visual axis of the left is moved in another plane common to the first and second points of views and its center of rotation, by the internus and superior rectus. The first and fourth conjugate centers act on their respective muscles as if they constituted one center, and the four muscles act as if they were but two—one for each eye—and the rotation plane of each one included the center of rotation of its eye and the first and second points of view. The four recti concerned, being normal in tonicity, make no demand on their respective basal centers. This oblique rotation could not be effected without interference with the all-important relationship of the vertical axes of the eyes and the median plane of the head, except for nature's provision for preventing it. The torsioning of both eyes would be to the right, but this is prevented by the eighth conjugate center, which

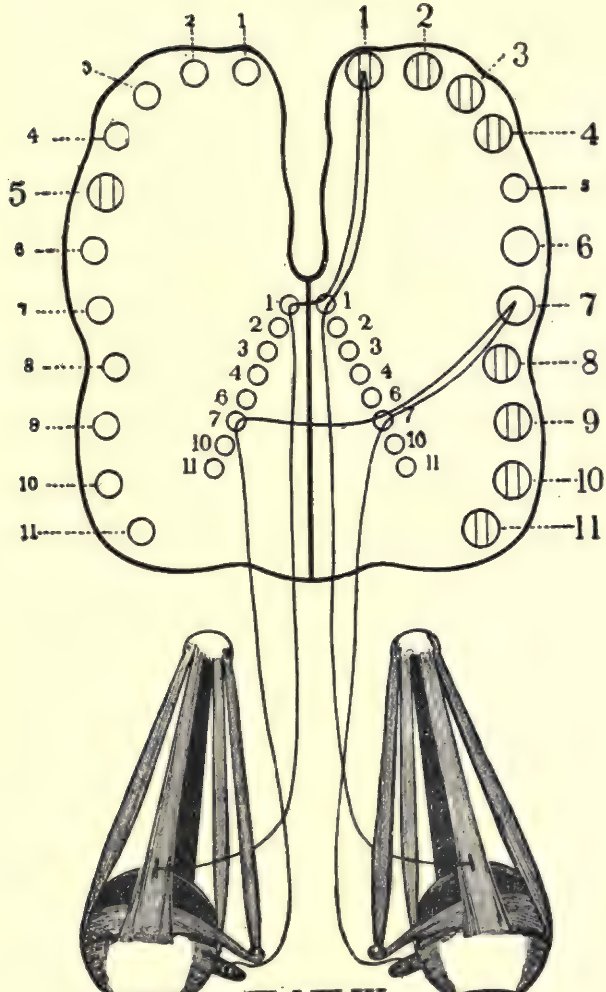


PLATE XI

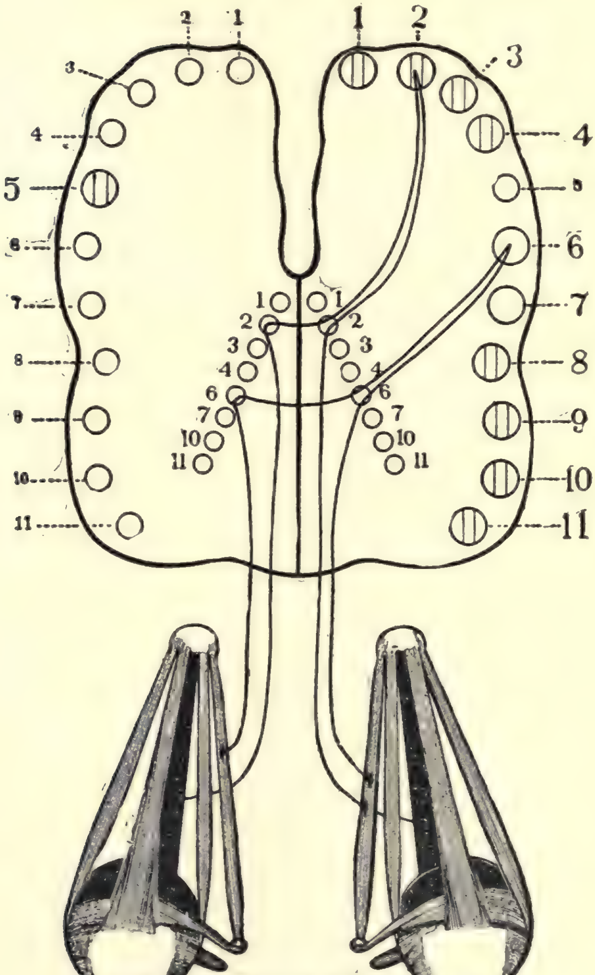


PLATE XII

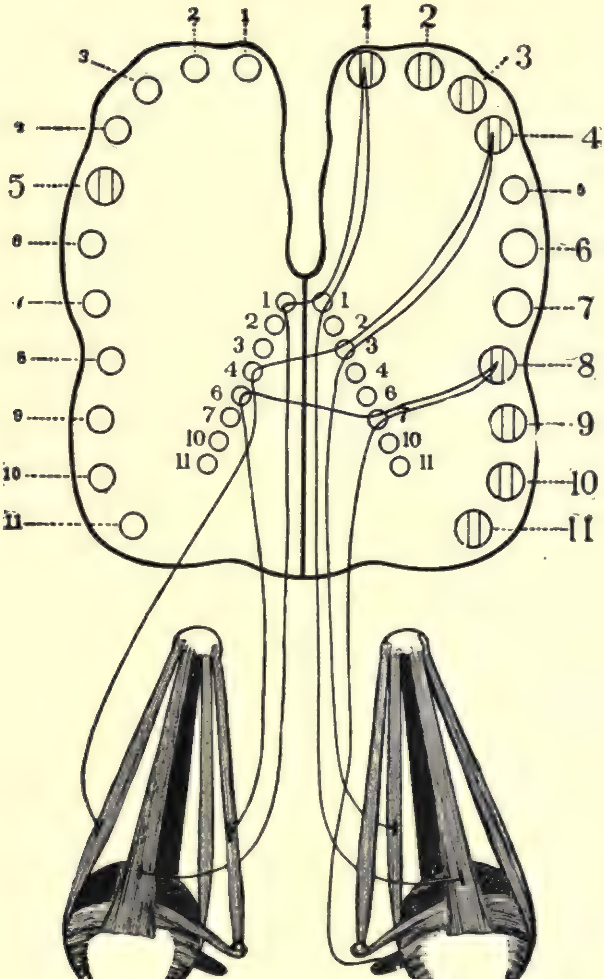


PLATE XIII

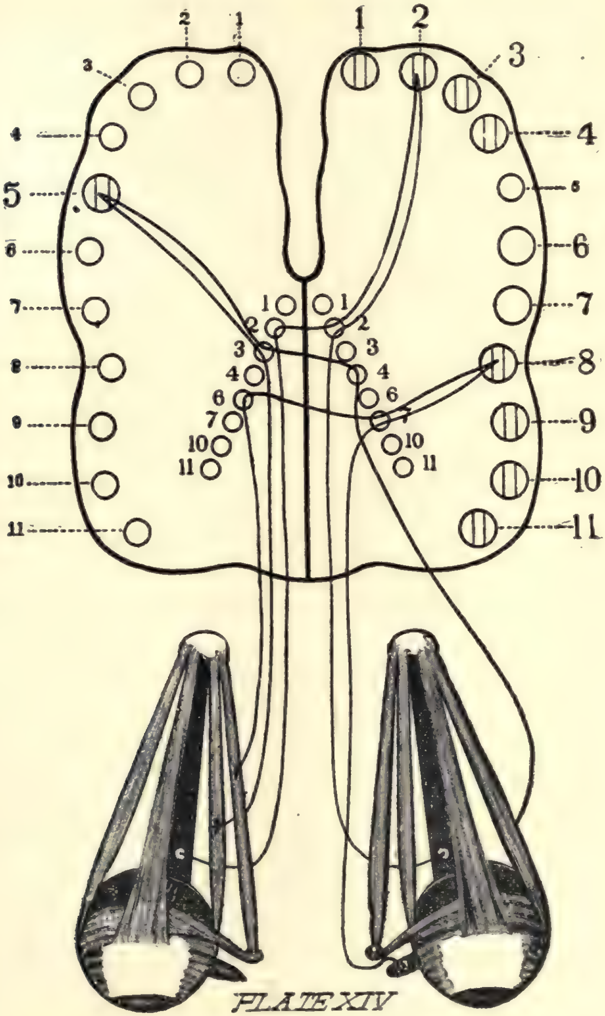


PLATE XIV

sends neuricity to the right superior oblique and left inferior oblique, their resulting contraction keeping the vertical axes parallel with the median plane of the head, while the first and fourth conjugate centers are effecting the oblique rotations. The six acting muscles are opposed by the other six, but the antagonism is that of tonicity and not contractility, hence all conjugate centers, except the first, fourth and eighth, are at rest, and not a basal center is active.

Plate XIV. represents the active centers and muscles that effect rotations of the two eyes down and to the left. A comparison of this plate with Plate XIII. will show that the same kind of torsioning results from simultaneous action of the second and fifth conjugate centers, as that caused by the combined action of the first and fourth conjugate centers, for the torsioning in each is prevented by the eighth conjugate center.

Plate XV. illustrates rotation upward and to the left by the action of the first and fifth conjugate centers on the two superior recti and on the left externus and right internus, respectively. The torsioning that would be to the left is prevented by the action of the ninth conjugate center on the left superior and right inferior obliques. In this, as in all oblique rotations of emmetropic-orthophoric eyes, the work is accomplished by six muscles under the influ-

ence of three conjugate centers, all other muscles and centers being free from activity.

Plate XVI. shows rotations of the two eyes down and to the right. The centers that cause this rotation are the second and fourth conjugate, and the torsioning that would occur is prevented by the action of the ninth conjugate center on the left superior and right inferior obliques. A comparison of Plates XV. and XVI. will show that the torsioning of both eyes would be to the left in oblique rotations up and to the left and down and to the right, for in each case it is prevented by the action of the ninth conjugate center on the left superior and right inferior obliques.

EMMETROPIA AND HETEROPHORIA.

Esophoria.—Plate XVII. represents a pair of esophoric-emmetropic eyes looking straight ahead at a point at practical infinity, the head being in the primary position. The tonicity of the interni being greater than the tonicity of the externi, the visual axes would tend to cross before reaching the point to be fixed. Such crossing would double the point. To prevent diplopia the fusion faculty of the mind unlocks the right and left fourth basal centers and the discharged neuricity excites just enough contractility of the two externi to neutralize the tonicity of the interni. No other brain centers, either basal or conjugate, are active, and all the muscles execpt the externi are at rest.

Plate XVIII. shows the same pair of eyes in the act of

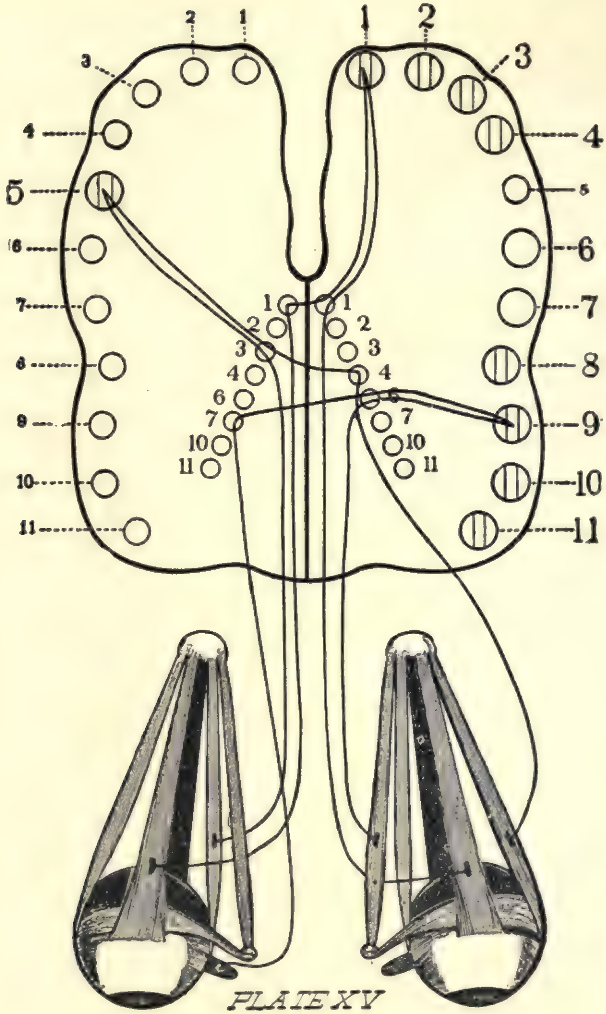


PLATE XV

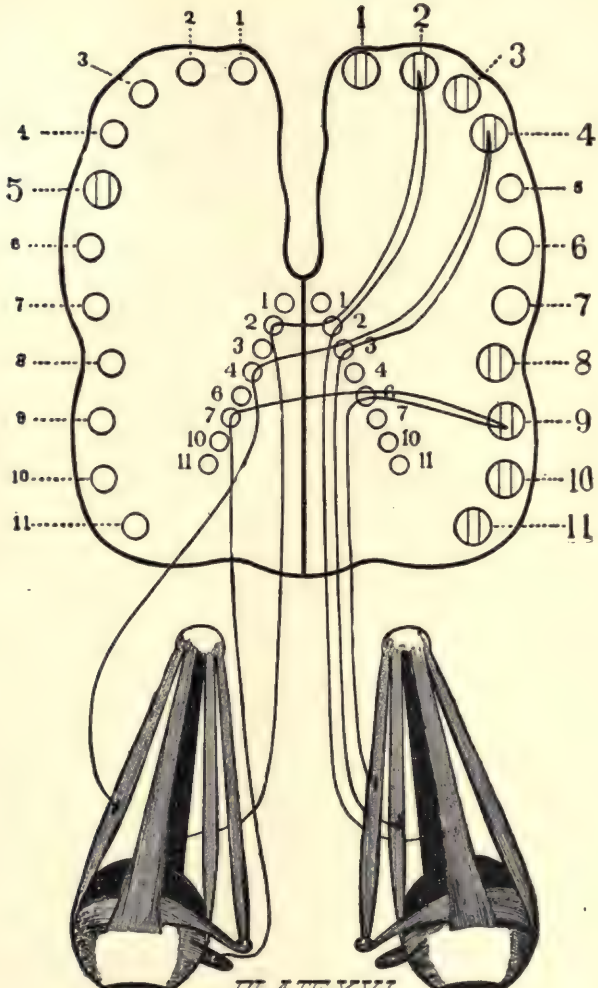


PLATE XVI

accommodation-convergence. A contrast of this plate with Plate VIII. will show that the only difference between accommodation-convergence of orthophoric and esophoric eyes, is that, in the latter, the right and left fourth basal centers must act on their respective externi to prevent the diplopia which would result if the interni were allowed to cross the visual axes too soon.

Plate XIX. shows the same pair of eyes making right version, under the influence of the fourth conjugate center, the visual axes being parallel. By contrasting this plate with Plate IX., one can readily see the additional work the brain must do in effecting the right sweep of esophoric eyes, above what it has to do in rotating orthophoric eyes in the same direction. In Plate IX. the externi and the interni have the same tonicity, hence the equally divided impulse from the fourth conjugate center will make the one eye move as fast and as far as the other. In Plate XIX. the left internus has greater tonicity than the right externus. The equally divided impulse from the fourth conjugate center would make the strong left internus move its eye faster and further than the weak right externus would rotate its eye. The lagging behind of the right eye would cause diplopia, to prevent which the right fourth basal center discharges supplemental neuricity to the weak right externus, thus compelling it to move the right eye in harmony with the left.

Plate XX. shows the same pair of eyes in the effort to

rotate to the left—left version. Comparing this plate with Plate X., it will be seen in the latter that no basal center is excited in left version of orthophoric eyes, while in the former plate it is made plain that the left fourth basal center must send neuricity to the weak left externus to supplement that coming from the fifth conjugate center, in order that the weak externus may make its eye move in harmony with the right eye, whose internus is strong.

With head erect and eyes fixed on a point in line of intersection of the extended median and horizontal planes of the head, at practical infinity, the muscles of orthophoric eye are all at rest, for no brain center, either conjugate or basal, is discharging neuricity; but if the eyes are esophoric, the right and left fourth basal centers are forced, by the fusion faculty, to discharge neuricity to their respective externi, which are kept in a constant state of contraction to prevent diplopia. In the right and left sweep of orthophoric eyes volition alone acts, and on the fourth and fifth conjugate centers respectively; but in the same rotations of esophoric eyes volition alone would fail. To effect harmonious right version, the fusion faculty of the mind aids volition by acting on the right fourth basal center; and the same aid is rendered in left version by the fusion faculty acting on the left fourth basal center.

Volition unaided effects accommodation and convergence of emmetropic-orthophoric eyes; but in esophoria, volition

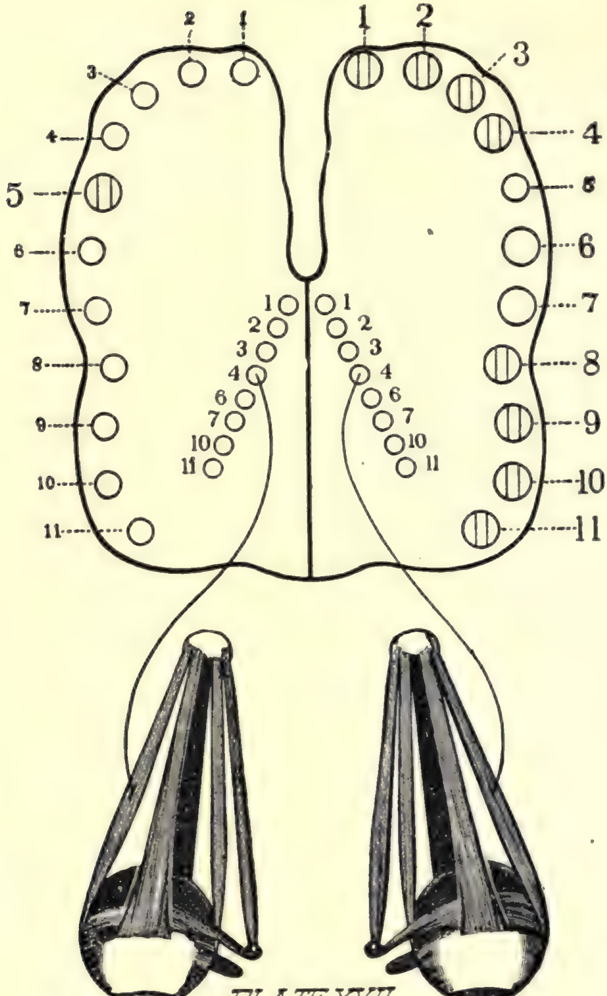


PLATE XVII

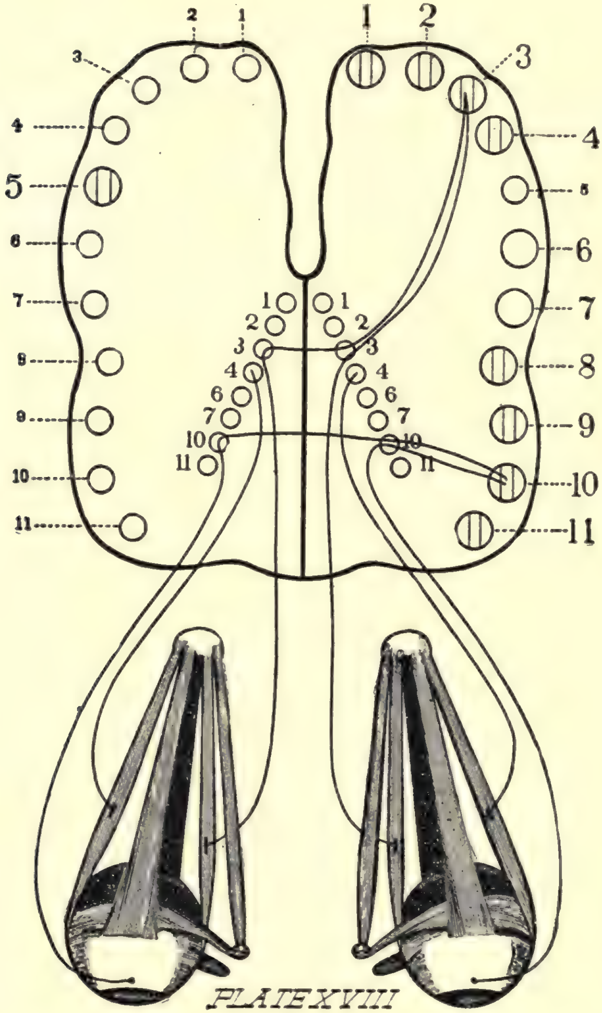


PLATE XVIII

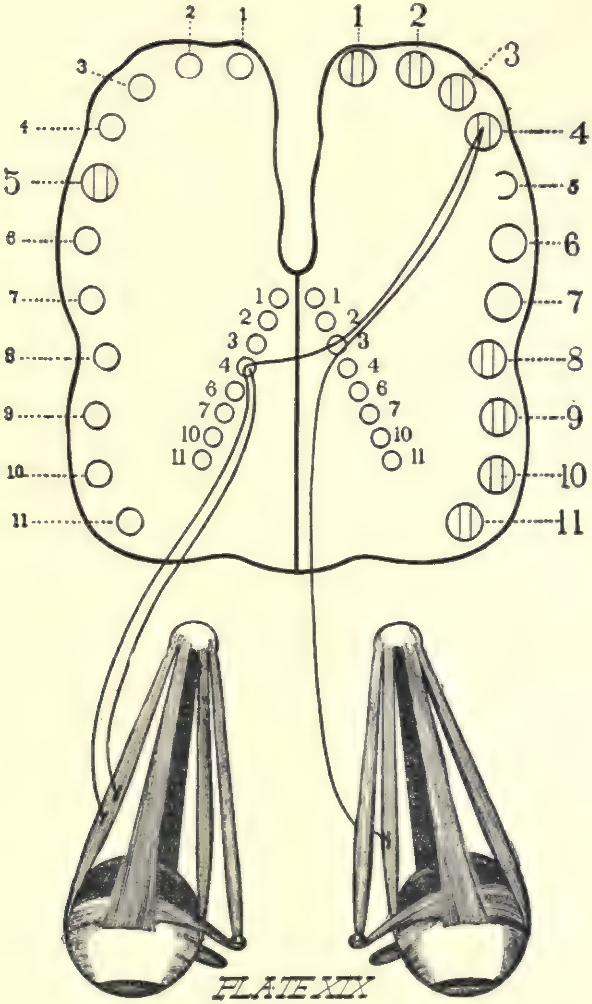


PLATE XIX

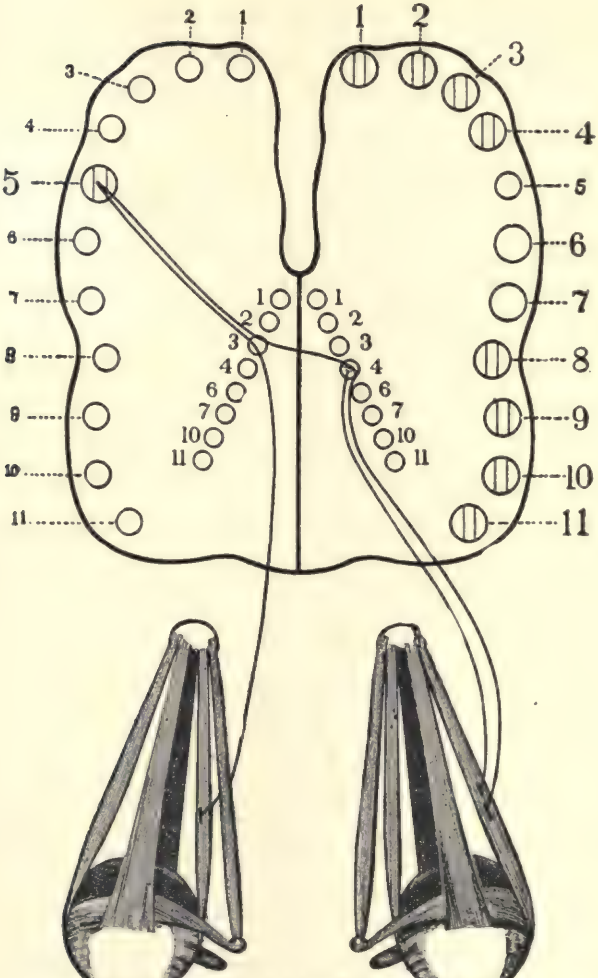


PLATE XX

must be aided by the fusion faculty of the mind, which calls into action the right and left fourth basal centers.

What is the source of trouble in esophoria? Certainly not the conjugate centers controlling the externi and the interni, for these centers do precisely the same work in esophoria as in orthophoria. If they develop no symptoms in the latter condition, they can cause none in the former. There are but two kinds of brain centers connected with the lateral recti, and since one class, the conjugate centers, cannot cause symptoms, in esophoria, or in any other form of heterophoria, then the centers belonging to the other class, the basal centers, must be chargeable. The basal centers of the interni, the right and left third centers, are never active in esophoria; but one or both of the right and left fourth basal centers must be in a constant state of activity in every case of esophoria, throughout every waking hour, and the externus connected with an active fourth basal center must be in a constant state of contraction. The basal center discharges neuricity, and the weak muscle contracts under this stimulus, in the interest of fusion—of binocular single vision. The excited basal centers, right and left fourth, and the contracting external recti muscles, one or both, develop all the symptoms that present themselves in esophoria.

Treatment of Esophoria.—All treatment should aim at bringing about such a condition of the lateral recti muscles

and the brain centers connected with them as will enable the third, fourth and fifth conjugate centers, under the influence of volition, to perfectly control the external and internal recti, unaided by the right and left fourth basal centers, whose normal state is restfulness. This can be done in one of three way: First, a prism before each eye, the strength equally divided, and the base of each out, the two completely correcting the esophoria, would allow both eyes to assume positions that would make the tonicity of the weak externus balance the tonicity of the strong internus, without diplopia. These prisms would relieve the right and left fourth basal centers of any necessity for action—would place them at rest, in direct distant vision, and in convergence, but not in versions. But there are two objections to prisms for esophoria, especially to strong prisms: one is that they always interfere with the law of direction; the other is that unless the interni are ideally attached to the sclera, either a plus or minus cyclophoria would be caused by the prisms. The first of these objections always exists, and the second is not uncommon, and is always serious.

The second plan of treatment is to develop the weak externi, by means of rhythmic exercise, so as to make their tonicity equal the tonicity of the interni. This would certainly and effectively relieve the right and left fourth basal centers of any demand for activity—would place them at

rest. Patience and perseverance are the essential factors in carrying out this plan of treatment.

The third plan of treating esophoria is to give equal tonicity by operations. This is the quickest, and, if the error be great, it is the best method. This result can be accomplished by weakening the two interni by partial tenotomies, or by strengthening the two externi by shortening or advancement. In the higher degrees of esophoria, tenotomies of both interni and shortenings of both externi must be done in order to relieve the two fourth basal centers. In doing these operations, the aim should be rather to fall short of a full correction than convert an esophoria into an exophoria.

All emmetropes, regardless of age, who have esophoria, may be benefitted by wearing convex lenses for all near work. These lenses lessen the demand on the tenth conjugate center, and correspondingly lessen the activity of the third conjugate center. The smaller quantity of neuricity sent to the interni excites a slighter contraction of these muscles, and thus the esophoria in the near is lessened if not relieved. About 2° of esophoria in the near is relieved by a +1 D. lens. Convex lenses should be given, for near work, to young emmetropes who are esophoric, only when prisms, exercise and operations are declined. Convex lenses would not alter the esophoria of emmetropes, in distant seeing.

Exophoria.—Plate XXI. represents a pair of emmetropic-exophoric eyes and the brain centers that must control them in straight-forward distant vision. The head is in the primary position, and the point to be fixed is at practical infinity and in the line of intersection of the extended median and horizontal planes of the head. The externi, having greater tonicity than the interni, would cause the visual axes to diverge, and the point of view would be doubled. To prevent this the fusion faculty of the mind causes the right and left third basal centers to send neuricity to their respective interni, that their tonicity may be supplemented by enough contractility to prevent the divergence of the visual axes. Contrasting Plate VII. with this plate, it will be seen that, in the former, all brain centers are at rest, and that no muscle is active, while in the latter the right and left third basal centers are discharging neuricity continuously to the weak interni, and that these muscles are just as continuously in a state of contraction. All other centers and muscles are just as restful in Plate XXI. as in Plate VII. Exophoric eyes that are emmetropic give trouble, in distant vision, only because of the work of the right and left third basal centers and the consequent contraction of the interni.

Plate XXII. represents the same pair of eyes in the act of accommodating and converging. A comparison of Plate

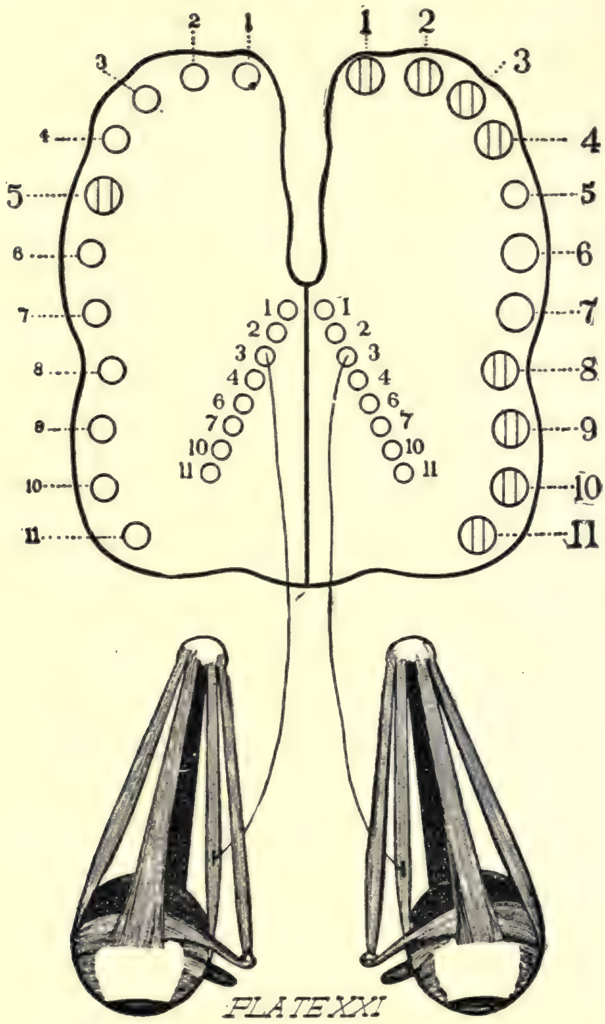

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PLATE XXI

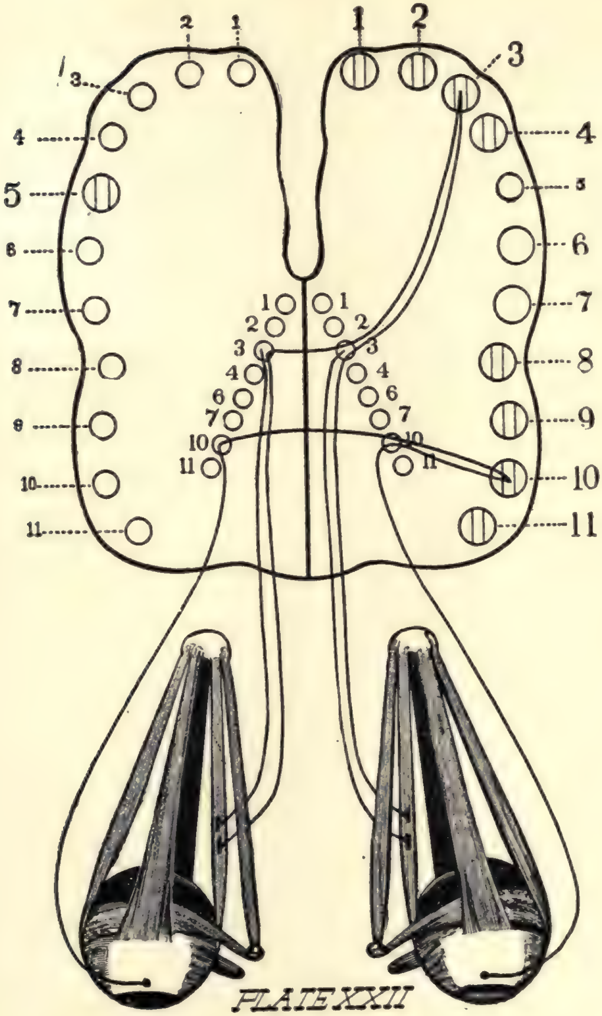

PLATE XXII

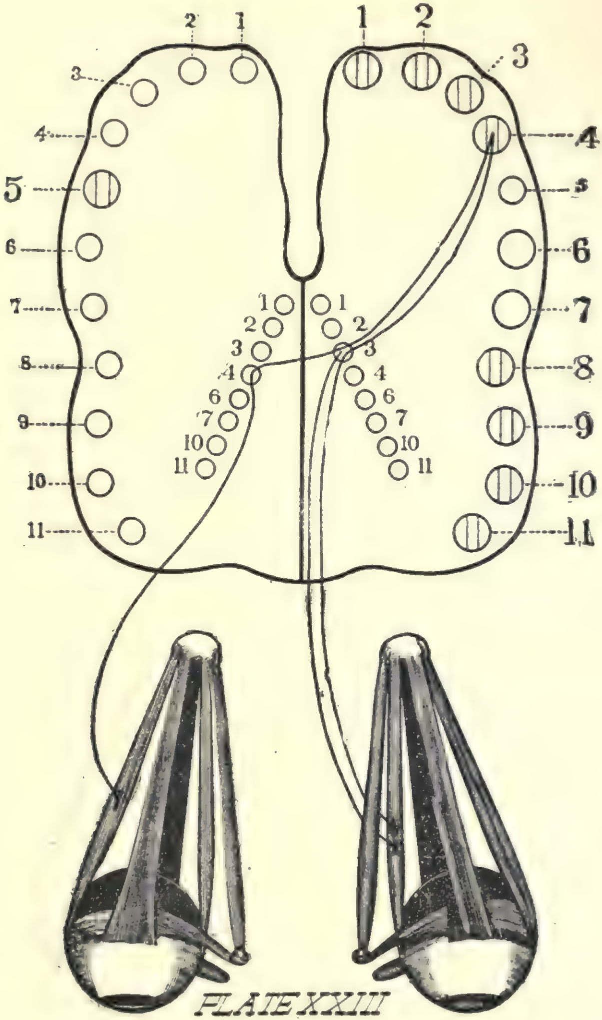

PLATE XXIII

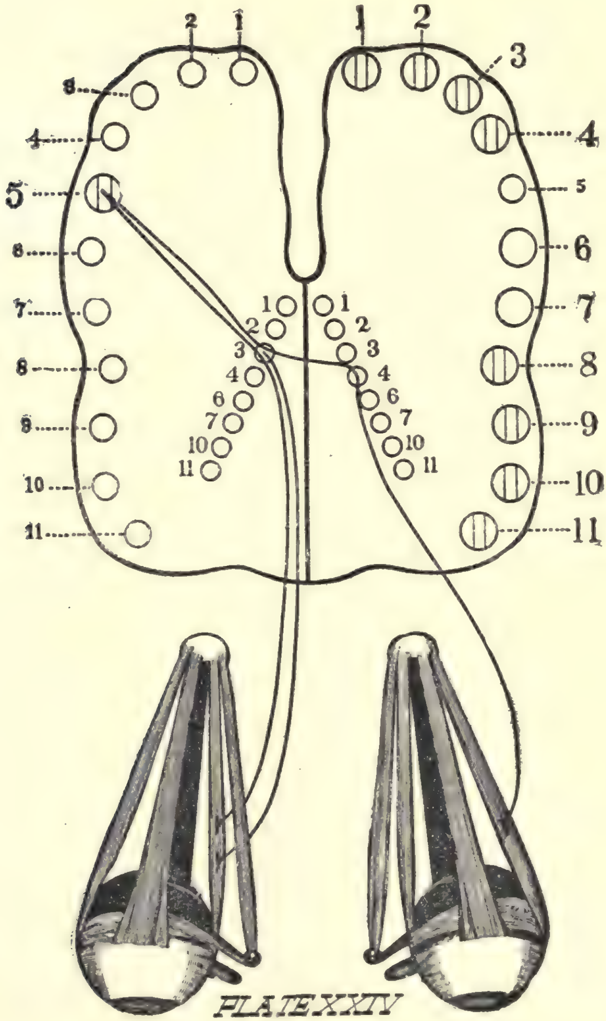

PLATE XXIV

VIII. with this Plate: the only difference shown is that, in the latter, lines have been drawn from the right and left third basal centers to the interni to show that both the centers and the muscles are active. The work being done by the third and tenth conjugate centers in Plate XXII. is precisely the same that is being done by these centers in Plate VIII. The symptoms caused by the use of emmetropic-exophoric eyes in near work must be chargeable against the corrective activity of the right and left third basal centers and the added contractility of the two interni.

Plate XXIII. represents the same eyes in the act of right version. The fourth conjugate center that effects right version, in perfect harmony, in Plate IX., cannot do so in Plate XXIII., for the reason that the tonicity of the right externus is greater than that of the left internus. That the left eye may rotate to the right in harmony with the fellow eye, its weak internus must receive supplemental neuricity from the left third basal center. In the right rotation of esophoric eyes the fourth conjugate center does precisely the same work that it performs in effecting the same rotation of orthophoric eyes, hence it cannot cause symptoms in the former and not cause them in the latter. Symptoms therefore, must be caused by the excited left third basal center and the consequent extra contraction of the left internus.

Plate XXIV. represents the same eyes in the act of left

version. The left externus having greater tonicity than the right internus, it would be impossible for the fifth conjugate center to effect harmonious left version. To prevent diplopia, the right third basal center must send supplemental neuricity to the weak right internus. Plate X. represents the normal conditions in left version. The difference between Plates X. and XXIV. must be the abnormality shown in the latter. This difference is activity of the right third basal center and the added contractility of the right internus. Cure the exophoria by either exercise of both interni or by partial tenotomy of both externi or by shortening both interni, then the right third basal center will not become active in left version of the eyes, the only active center being the fifth conjugate. Concave lenses for both distant and near vision would relieve the two third basal centers by exciting the third conjugate center.

Hyperphoria and Cataphoria.—Plate XXV. represents a pair of eyes, the left being hyperphoric and the right cataphoric, the gaze being straight-forward and the point of fixation in the line of intersection of the extended median and horizontal planes of the head, at practical infinity. No conjugate center is excited; but, to keep the visual axes in the extended horizontal plane, the right first basal center must send neuricity to the weak right superior rectus, and the left second basal center must send neuricity to the weak

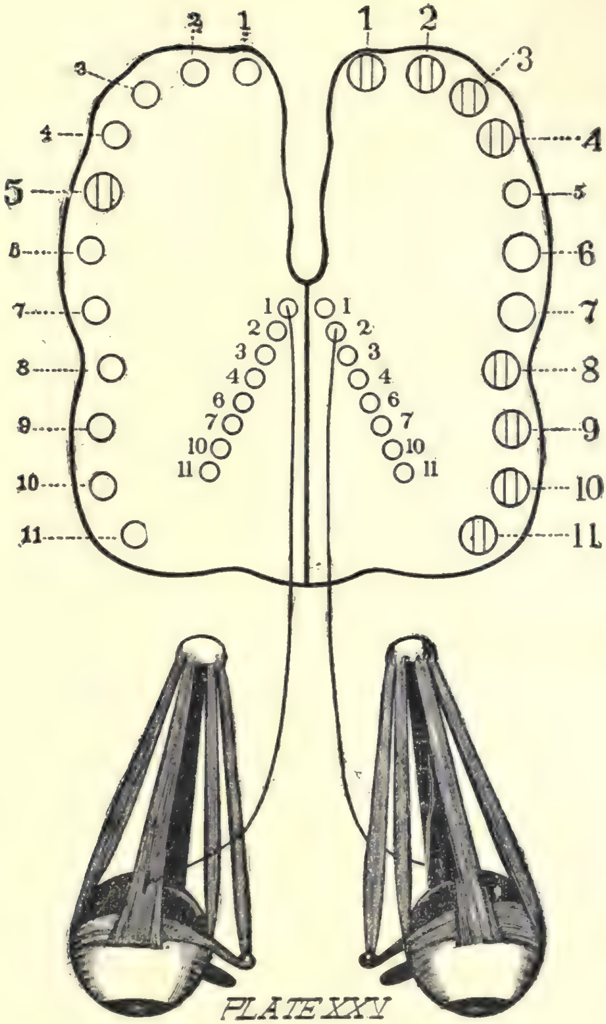
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PLATE XXV

left inferior rectus. Otherwise there would be diplopia. Correct this error by either exercise or operations, then these two basal centers would lapse into their normal state of rest. The result—restful state of both muscles and brain centers—would be represented by Plate VII.

Plate XXVI. represents the upward version of the same pair of eyes. The first conjugate center sends an equal amount of neuricity to both superior recti, but with unequal results. The tonicity of the left superior rectus being greater than that of the right superior rectus, the right eye would not rotate as fast as the left unless supplemental neuricity should be sent by the right first basal center to the weak right superior rectus. In upward version the seventh conjugate center is active to prevent inward torsioning of the eyes. The abnormal work done by both brain and muscle in the upward rotation is shown by contrasting Plate XXVI. with Plate XI, the latter showing the upward rotation of orthophoric eyes. This abnormality consists of activity of the right first basal center and the excessive contraction of the right superior rectus. If the first and seventh cortical centers cause no symptoms in the upward rotation of orthophoric eyes, these centers, doing precisely the same work in superverting hyperphoric and cataphoric eyes, as shown in Plate XXVI., can cause no symptoms. The discomfort, therefore, must come from excitation of the right first basal center and the resulting excessive con-

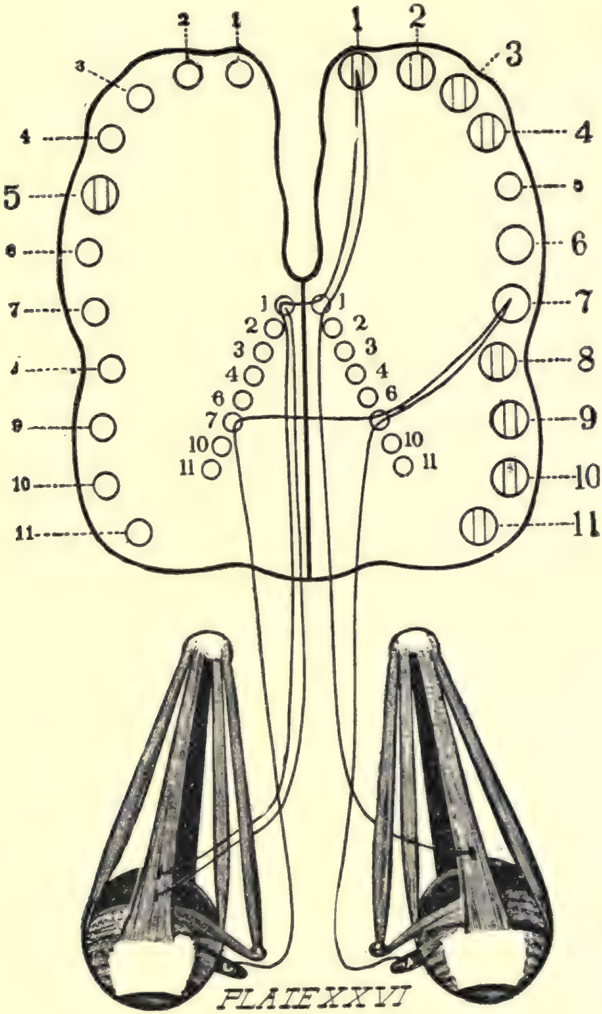

PLATE XXVI

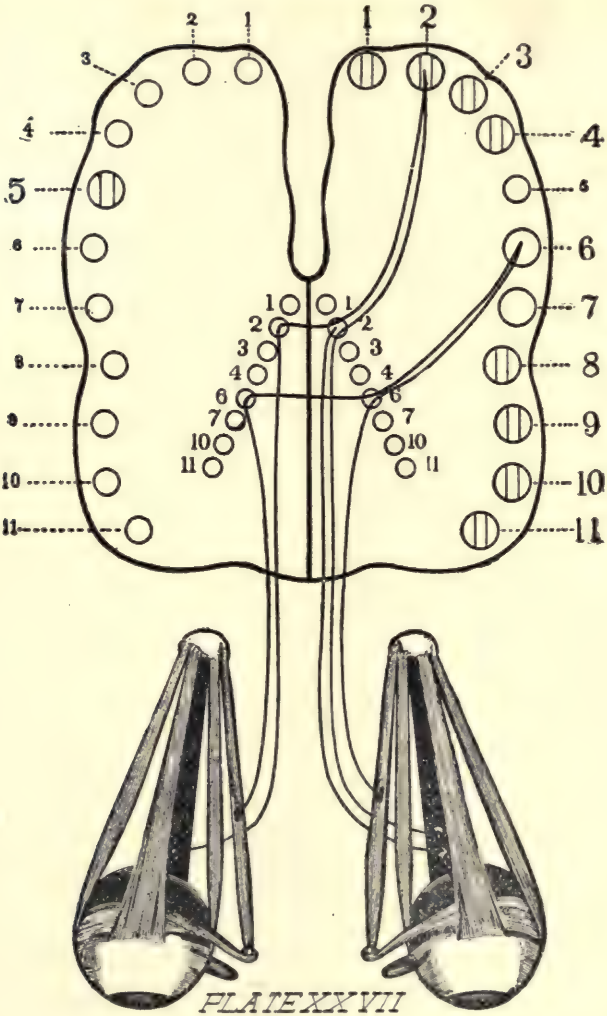

PLATE XXVII

traction of the right superior rectus. Giving equal tonicity to the superior and inferior recti by either exercise or operations, allows the right first basal center to remain inactive in the upward rotation, hence there could be no symptoms.

Plate XXVII. represents the downward rotation of the same pair of eyes. The abnormal action in this plate can be easily seen by contrasting it with Plate XII., which represents the active brain centers and contracting muscles in the subversion of orthophoric eyes. In the downward version shown in Plate XXVII. the left inferior rectus must receive supplemental neuricity from the left second basal center, or there would be diplopia. The second and sixth conjugate centers act on hyperphoric eyes as they act on orthophoric eyes, hence they do not excite symptoms of any character. Equalizing the tonicity of the superior and inferior recti of the eyes shown in Plate XXVII. converts this plate into Plate XII.

Plus and Minus Cyclophoria.—Plate XXVIII. represents a pair of eyes having plus cyclophoria. The head is in the primary position, and the eyes are also in their primary positions. The recti muscles are all normal in tonicity, hence, without brain excitement, the visual axes lie in the extended horizontal plane and are practically parallel with each other. The inferior obliques having greater tonicity than the superior obliques, would cause both vertical axes

to deviate from the median plane of the head, and there would be diplopia. If the error is equal in the two eyes, the sixth conjugate center acting alone can prevent the diplopia by sending an equal quantity of neuricity to the weak superior obliques. This is shown in the plate. If the right superior oblique should be weaker than the left, the right sixth basal center would have to send supplemental neuricity to this weaker muscle in order that the two might act in harmony. The sixth cortical center and the right and left sixth basal centers are all under the control of the fusion faculty of the mind. Correcting the plus cyclophoria by exercising the superior obliques transforms Plate XXVIII. into Plate VII, and all symptoms must disappear. Relief will also attend the placing of either plus or minus cylinders, given for the correction of astigmatism, in positions of rest for the weak superior obliques.

It is not improbable that plus cyclophoria is entirely corrected by activity of the right and left sixth basal centers, and, if so, Plate XXXVI. should be substituted for Plate XXVIII.

Plus cyclophoria is corrected in superversion by the action of the first conjugate center on the superior recti, for these muscles in raising the eyes would counteract the tendency towards outward torsion, thus relieving the sixth conjugate center, or the right and left sixth basal centers, and the superior obliques. The seventh conjugate center

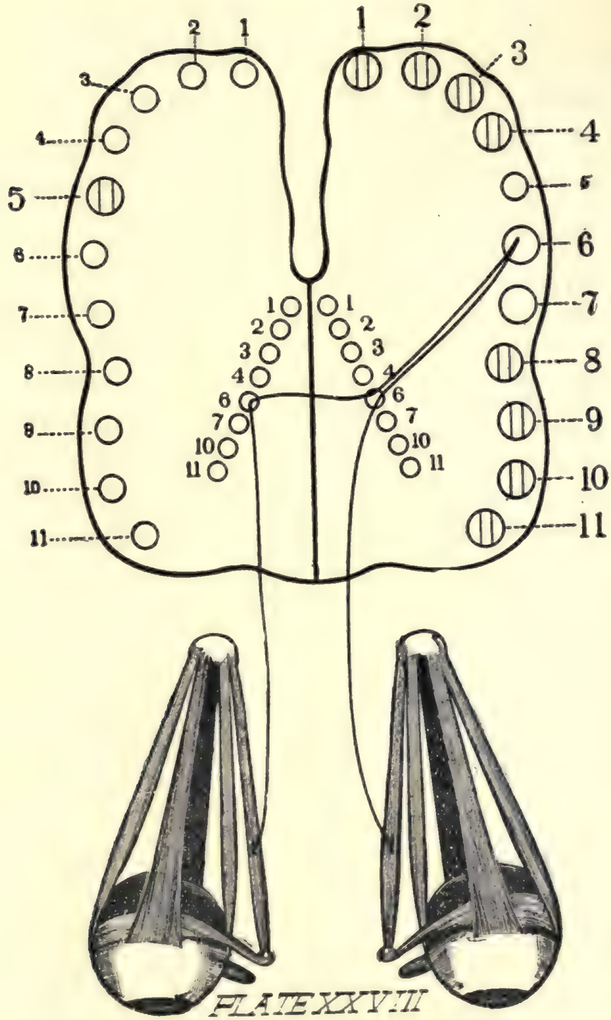

PLATE XXVIII

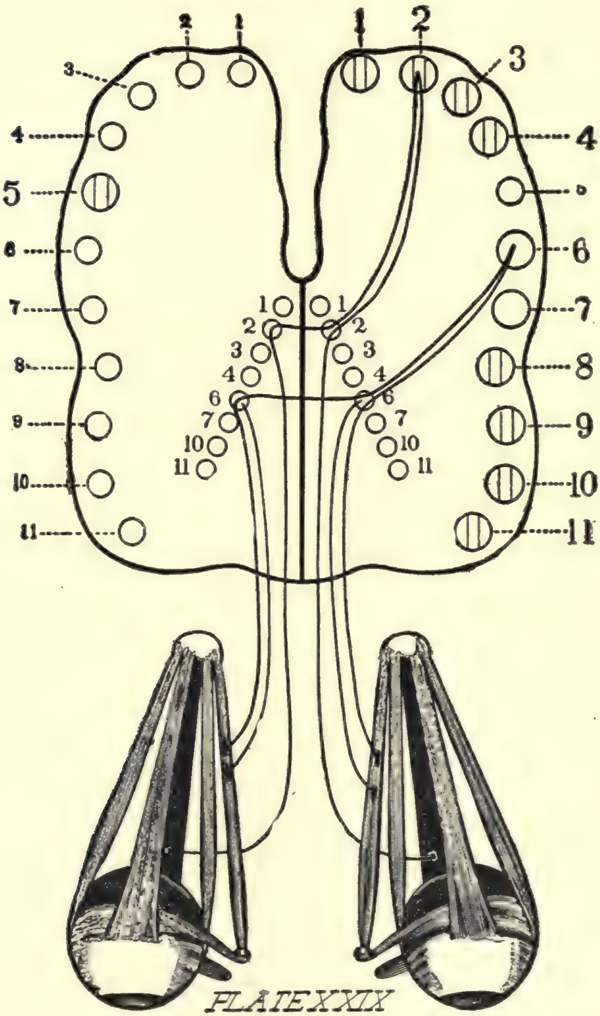

PLATE XXIX

and the inferior obliques take a smaller part in superversion when there is plus cyclophoria than when there is orthophoria of the obliques.

Plate XXIX. shows the centers and muscles concerned in subversion of eyes that have plus cyclophoria. The second cortical center acting on the inferior recti would rotate the eyes down and produce an excessive plus torsioning because of the already existing plus cyclophoria. It may be supposed that the sixth cortical center would so act on the weak superior obliques as to help the inferior recti depress the eyes and correct the torsioning error of the latter, leaving the correction of the plus cyclophoria to the right and left sixth basal centers. Thus it is shown that weak superior obliques have to do excessive work whenever the point of fixation is below the horizontal plane, and that the extra neuricity demanded comes from the right and left sixth basal centers that ought to be at rest. Correction of the plus cyclophoria by exercising the superior obliques, or by properly shifting the axes of plus or minus cylinders given for the correction of astigmatism, relieves these basal centers in reading or other near work. The only additional means of relief to the centers and to the weak superior obliques is in depressing the head so that the extended fixed horizontal plane of the head may fall below the plane of the visual axes. A person with uncomplicated plus cyclophoria habitually carries his head with his face cast down,

as also does the one with double hyperphoria. Such a person should be treated for his physical defect and not condemned because of a supposed mental obliquity. The relief of the plus cyclophoria transforms Plate XXIX. into Plate XII., the latter illustrating the downward sweep of orthophoric eyes.

Plate XXX. represents a pair of minus cyclophoric eyes, both the head and the eyes being in their primary positions, the point of fixation in the line of intersection of the extended median and horizontal fixed plane of the head and at practical infinity. All of the recti muscles and the two superior obliques are in a state of tonicity, and the cortical and basal centers connected with them are at rest; but to maintain parallelism between the vertical axes of the eyes and the median plane of the head, the seventh conjugate center or the right and left seventh basal centers must send neuricity to the weak inferior obliques so that contractility may supplement tonicity, thus enabling them to perfectly balance the stronger superior obliques. A cure of the minus cyclophoria by exercise, or correcting it by properly shifting plus or minus cylinders, converts Plate XXX. into Plate VII. The upward gaze of minus cyclophoric eyes makes excessive demands on the inferior obliques, and the seventh conjugate and right and left seventh basal centers controlling them. Minus cyclophoria is probably entirely corrected by activity of the right and left seventh basal cen-

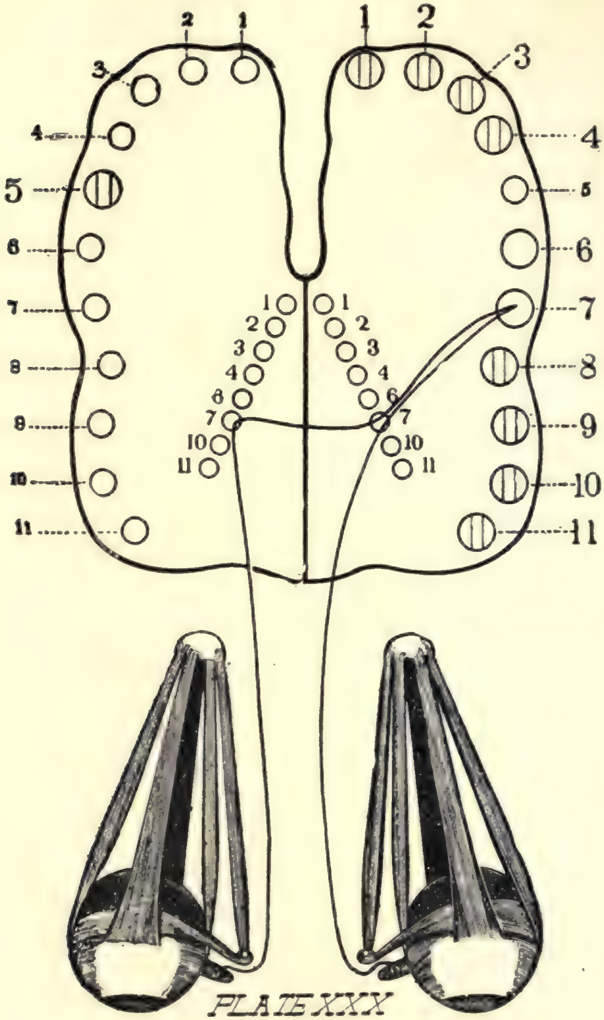

PLATE XXX

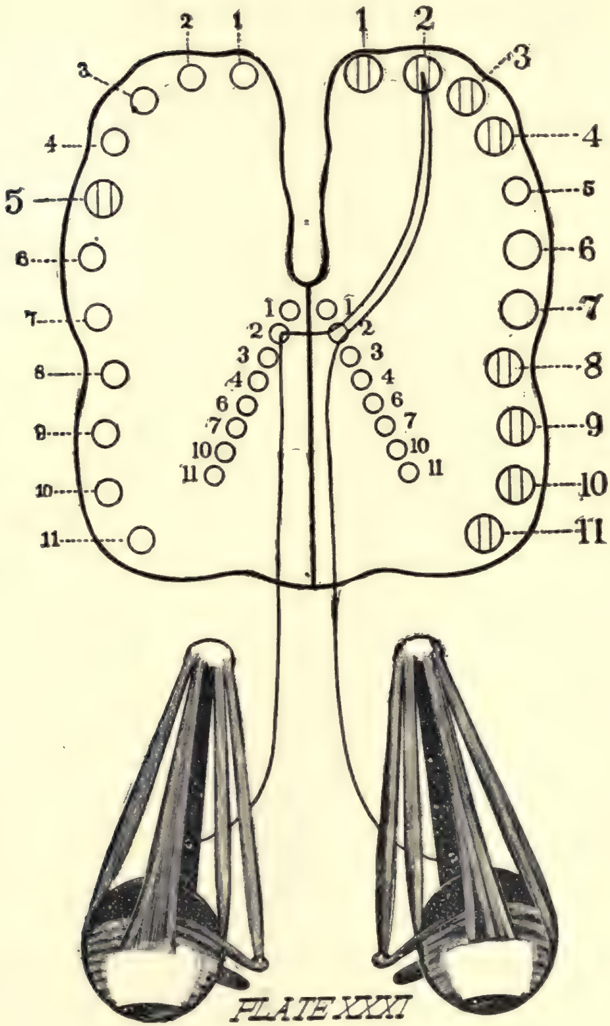

PLATE XXXI

ters, and, if so, Plate XXXVII. should be substituted for Plate XXX.

Plate XXXI. shows that when the point of view is below the extended horizontal plane of the head, the brain centers and muscles have less to do, if there is minus cyclophoria, than when there is orthophoria. This can be seen at a glance by contrasting Plate XXXI. with Plate XII. In Plate XXXI. the outward torsioning effect of the inferior recti only counteracts the minus cyclophoria. There is no need for excitation of the sixth conjugate center, because the tonicity of the strong superior obliques will prevent an outward torsioning by the inferior recti under the influence of the second conjugate center. The person who has uncomplicated minus cyclophoria, like the one who has double cataphoria, carries a high head, usually erroneously thought to be indicative of a proud spirit.

Up to this point the several heterophoric conditions have been studied as if only a single one existed in any given case. The truth is, that two or more of these errors very often co-exist, thus complicating the case both as to the number of basal centers that must be active, and the number of muscles that must be continually in a state of contraction. Combined errors are more likely to cause symptoms than is a single error.

A combination of Plates XVII. and XXV. will show that, in hyper-esophoria, four basal centers must be continually

discharging neuricity to their respective muscles, that diplopia may be prevented. A combination of Plates XVII., XXV. and XXVIII. will show that, in hyper-esophoria complicated with plus cyclophoria, six basal centers and their six muscles must be active in the interest of binocular single vision. In all these plates the eyes represented are in their primary positions and the head is erect. The restfulness of brain centers and muscles of orthophoric eyes, the head and eyes being in their primary positions, is shown in Plate VII. Orthophoria is harmless for the reason that no basal center is ever awakened from its normal state of restfulness; all heterophoric conditions are harmful for the reason that one or several basal centers and their respective muscles must be continually active for the prevention of diplopia, throughout all the waking hours of every day of one's life. Withdrawal from near work brings rest to orthophoric eyes and to the conjugate centers connected with them; there is no rest for heterophoric eyes nor for the basal centers connected with the weaker muscles, except in sleep.

In right version of hyper-esophoric eyes three basal centers,, the right fourth, the right first and the left second, will be actively combating diplopia. This can be seen by combining Plates XIX. and XXV., for the latter plate represents the action of the right first and left second basal centers not only in the straight-forward gaze, but also in

both right and left version as well. One conjugate center, the fourth, is alone concerned in the right version of orthophoric eyes, as shown in Plate IX.; but, as shown above, the right sweep of hyper-esophoric eyes is effected by activity of the same conjugate center, the fourth, but there is also associated activity of three basal centers.

In the straight-forward gaze of hyper-eso-plus-cyclophoric eyes (the left eye being hyperphoric), four, if not six, basal centers are active, the right and left fourth, the right first and left second, and probably the right and left sixth, although the sixth conjugate center could do the work of keeping the vertical axes of the eyes parallel with the median plane of the head. These excited centers can be seen by a mental combination of Plates XVII., XXV. and XXVIII. The restfulness of muscles and brain centers in direct vision when there is orthophoria, can be appreciated to the fullest by now glancing at Plate VII. To relieve the basal centers in any form or heterophoria or in any combination of heterophoric conditions, the relationship of the recti muscles must be readjusted either by operations, by exercise or by prisms in positions of rest; and that of the obliques must be readjusted by means of cylinders for either exercise or rest, or by so operating on a rectus muscle as to relieve the cyclophoria.

Not more than three conjugate centers are ever active in effecting ocular rotations, whether the eyes are ortho-

phoric or heterophoric. All possible rotations of orthophoric eyes are accomplished without excitation of a single basal center. Heterophoric eyes can assume no position and maintain binocular single vision, without excitation of from one to six basal centers. The exact basal centers disturbed in any given rotation of simple or complicated heterophoric eyes may be easily determined. For every disturbed basal center there is abnormal contraction of an ocular muscle. If six basal centers are simultaneously disturbed, six muscles are made to respond for the prevention of diplopia.

It is an interesting fact to note that, in cases of heterophoria, fewer basal centers are excited when the point of view is secondary than when the eyes and head are in their primary positions. This is shown in Plates XVII., XIX. and XX., illustrating three positions of esophoric eyes. To determine that the same thing is true of exophoric eyes, one need only examine Plates XXI., XXIII. and XXIV. This truth is also made clear as to hyper-cataphoria by examination of Plates XXV., XXVI. and XXVII. It is further remarkable that, while the primary position of heterophoric eyes disturbs the largest number of basal centers, the same position allows all conjugate centers to lapse into a state of repose. Since in orthophoric eyes no basal center is ever excited, it must appear that in the primary positions of such eyes there is absolute restfulness of all

conjugate and basal centers, and consequent inaction of all the ocular muscles. This is shown in Plate VII., already frequently referred to.

The muscle errors so far studied may be classed as true heterophoric conditions, in contrast with other errors to be studied later under the name of pseudo-heterophoria. The cause of every form of true heterophoria is muscular. It must appear, therefore, to every careful student that the treatment of every form of true heterophoria must be directed to the muscles. Whatever the method of treatment may be, the aim should be to equalize the tonicity of opposing muscles, so that the basal brain centers may lapse into that state of rest which is normal to them when eyes are orthophoric. To determine what plan of treatment shall be adopted in any given case, the surgeon should resort to the tonicity, version and duction tests, as set forth in the first chapter of this book. Rhythmic exercise of the weaker muscles will accomplish this purpose, in suitable cases, by increasing their tonicity; in other cases, shortening or tucking the weaker muscles will increase their tonicity up to the point desired; in still other cases partial tenotomies of the stronger muscles will lessen their tonicity, so that they may perfectly balance the tonicity of their antagonists. Since the author intends this little book only as a companion volume to his other book, *Ophthalmic Myology*, the reader is referred to the latter for an ex-

tended and trustworthy study of methods of treatment. A study of true heterophoria from the brain side of the question has but emphasized the teaching in *Ophthalmic Myology,* that all treatment must be directed to the muscles.

A fitting conclusion to this chapter will be a study of multiple errors that may be caused by one muscle, and how to treat such a muscle. If a too strong internus is attached too high, the error causes both a hyperphoria and a minus cyclophoria, as well as esophoria. If it is attached too low, this error causes both a cataphoria and a plus cyclophoria, as well as esophoria. If a too strong externus is attached too low, this error will cause a cataphoria and a minus cyclophoria, as well as exophoria. If attached too high, this error will cause a hyperphoria and a plus cyclophoria, as well as exophoria. A too strong superior rectus attached too far nasal-ward will cause esophoria and plus cyclophoria, as well as hyperphoria. A too strong inferior rectus attached too far nasal-ward will cause an esophoria and a minus cyclophoria, as well as cataphoria; but if attached too far temple-ward it will cause an exophoria and a plus cyclophoria, as well as cataphoria. A knowledge of the heterophorias affecting the superior and inferior recti and the two obliques is of supreme importance in connection with operative work on the lateral recti muscles, for the cure of intrinsic heterophorias affecting them. How to operate with the view of altering the tension of a rectus muscle, with or

without changing its plane of rotation, is fully set forth in *Ophthalmic Myology,* to which the reader is again referred. To do a tenotomy on a lateral rectus muscle, or to shorten or advance it, without knowing whether or not its plane of rotation should be changed, is to err, which may be human, but certainly is not scientific. To fail to change the plane in making a tenotomy of an internus when there is a plus cyclophoria, whether the cause is in the obliques or in faulty attachment of a rectus muscle, is to leave uncorrected a most important error; to change the plane of an internus when there is no cyclophoria is to bring into existence a cyclophoria which will ever be a source of trouble. To determine the character of operation to be done on a rectus muscle may appear to be a difficult problem, but in reality it is easy of solution. The tonicity and duction tests of all the recti, and the tonicity test of the obliques, determine in every case whether the tonicity of the stronger rectus should be lessened by a partial tenotomy, or that the tonicity of its weak antagonist should be increased by a shortening or advancement; and these tests also determine whether or not the muscle plane should be changed.

Whence come the symptoms of heterophoria is a question that may never be satisfactorily answered. Do they come directly from activity of basal brain centers whose normal state is rest? Or do they come from the fusional contraction of the ocular muscles? There must be the two co-ex-

isting states: brain center excitation and muscle contraction. May not the forced activity of the fusion faculty of the mind for the time suspend, or otherwise interfere with, some other faculty of the mind—just as deep thinking may modify the faculty of hearing, or just as the mastery of an emotion may suspend the power of reasoning? Intense and unceasing activity of any one mental faculty must cripple, to a greater or less extent, every other mental faculty. Some faculty of the mind must preside over every organ of the body. It must appear that each of these faculties can do its best only when no other faculty is overtaxed. The fusion power is a mental faculty that presides over a little kingdom at the base of the brain, consisting of twelve individual centers, each of these centers being connected with a single ocular muscle. This mental power, as already shown, has nothing to do when the two eyes are orthophoric, hence could not be a source of interference with any other mental process. In heterophoria the fusion faculty must be continually active during all waking hours, hence may impair the effective working of any or all other faculties. Since correcting heterophoric conditions brings rest to the fusion faculty of the mind as well as to the basal centers and their respective muscles, such work should not be neglected.

Symptoms may arise from overwork of the weak ocular muscles, because of a ptomaine or, more correctly speaking,

a leucomaine, generated by their unremitting contraction. This substance, by its action on the sensory nerve endings in the muscles, may disturb the sensory area of the cortex, and thus excite the sensory symptoms of which such patients complain. It would hardly account for disturbance of secreting and excreting organs, for confusion of thought, and for convulsion seizures. But from whatever standpoint we may view the symptomatology of heterophoria, there can be but one logical conclusion as to treatment—that is, to readjust the relationship between the muscles, so that there may be equality of tonicity. From this readjustment by exercise or operations comes rest to the fusion faculty of the mind, rest to the basal centers, and rest to the muscles. Relief cannot come through the mind, nor as a result of any attempt, however impossible, to change the nature of the basal centers, so that work to them may be the same as rest. So long as there is unequal tonicity of the ocular muscles, binocular single vision will be possible only as the result of disturbed mental equilibrium, overworked brain centers, and unceasing muscle contraction.

From the standpoint of basal centers, none of the several kinds of heterophoria involving the recti muscles can exist in monocular vision, notwithstanding the fact that opposing muscles may be unequal in tonicity. Cyclophoria alone is a condition that is as important when there is only one eye as when there are two, for the vertical axis must be kept

parallel with the median plane of the head in both monocular and binocular vision, that there may be correct orientation. No basal center connected with a rectus muscle is ever active if there is but one eye. This explains the fact that many persons who have lost one eye by disease or accident, the condition being such as not to excite sympathy, have stronger and more comfortable vision with the one eye than they ever had with the two eyes. If nothing could be done for equalizing tonicity of the ocular muscles, to many individuals the loss of one eye would not be a misfortune.

"Two eyes are better than one" only when the muscles are well adjusted. Readjustment of unbalanced muscles is one of the great achievements of modern surgery.

CHAPTER III.

AMETROPIA AND PSEUDO-HETEROPHORIA.

Every form of ametropia has associated with it a pseudo-heterophoria, and they are related to each other as cause and effect. There is no pseudo-hyperphoria or cataphoria, nor is a pseudo-cyclophoria possible as a result of ametropia.

From what has been said above, it would appear that errors of refraction can affect, through the nerve centers, only the lateral recti muscles, and this is true. Pseudo-esophoria or pseudo-exophoria, one or the other, exists in connection with, and is caused by, every error of refraction. The higher the refractive error, the greater is the lateral pseudo-heterophoria. Pseudo-exophoria can show itself—can exist—only in the near. Pseudo-esophoria may exist in both far and near seeing.

The pseudo-errors of the lateral recti muscles may exist alone or in combination with either intrinsic esophoria or intrinsic exophoria. If there is pseudo-esophoria it may show itself as an esophoria when there is lateral orthophoria, or it may increase an existing intrinsic esophoria., or it may simply lessen, cancel or conceal an intrinsic exopho-

ria. In the first and second instances the pseudo-esophoria is a bad thing and should be cured by correcting the focal error causing it; in the latter instance the pseudo-esophophoria is a blessing, in that it brings some relief to the right and left third basal centers, and, for that reason, the focal error causing it should not be corrected.

Remembering that pseudo-exophoria exists only in the near, it may be said that this may show itself as exophoria when there is true orthophoria; it may show itself as an increased exophoria because of an existing intrinsic exophoria, or it may in part or wholly neutralize or conceal an intrinsic esophoria. In the first and second instances, the error is an evil, and should be cured by a correction of the focal error causing it; but in the third instance it is a blessing, in that it relieves the right and left fourth basal centers of the hard task they otherwise would have to perform in reading or other near work. Thus it would appear that focal errors are sometimes a blessing, though more often they constitute an evil.

MYOPIA.

Myopia and Orthophoria.—Plate VII. shows the brain rest and muscle inaction of myopic-orthophoric eyes, when the object of view is at infinity, and in line of intersection of the extended median and horizontal fixed planes of the head. Such eyes, so far as distant vision is concerned, give

the same rest to conjugate and fusion brain centers, and the muscles under their control, as do emmetropic-orthophoric eyes, the only difference being in the sharpness of sight. Sharpening distant vision, by giving the proper concave lenses, would create no demand for activity of the muscles or the brain centers controlling them. These lenses would make the eyes emmetropic and leave them orthophoric for distance. The lenses would make the eyes emmetropic for near work and would also make them orthophoric in the near, by relieving the pseudo-exophoria.

Plate XXXII. shows myopic-orthophoric eyes engaged in near work. Supposing the myopia to be 3-D, the ciliary muscles and the tenth conjugate center would be at rest when the point of view is at thirteen inches. There must be convergence, else there would be diplopia. If there is an unalterable relationship between the tenth and third conjugate centers, the latter could not discharge neuricity for effecting convergence, while the tenth center remains quiet. Nevertheless, convergence, by means of activity of the right and left third basal centers, would be possible, for these centers are not associated in action with the tenth conjugate center. If the basal centers (right and left third) converge myopic eyes, they do it in the interest of binocular single vision. This much is in accord with the supposition that convergence of myopic-orthophoric eyes is effected by the right and left third basal centers: if myopic eyes are

orthophoric in the distant test, they always show exophoria in the near. The third basal centers correct an exophoria whether of the true or the pseudo-type. There being room for some doubt as to how convergence of myopic eyes is effected, the illustration (Plate XXXII.) shows the third conjugate and the right and left third basal centers, all connected with the interni, each doing a part of the work. However this may be, the work is abnormal, and the myopic error causing it should be corrected—not under-corrected nor over-corrected. The myopia of orthophoric eyes, as shown in the distance test, should always be fully corrected. Another argument in favor of the convergence of myopic eyes being effected by the right and left third basal centers is the fact that, with the correcting lenses on, the pseudo-exophoria disappears. The convergence and accommodation of corrected myopic eyes are correctly represented in Plate VIII. If the third conjugate center takes no part in convergence except when the tenth center is active, then Plate XXI. illustrates the convergence, not only of myopic eyes, but also of presbyopic eyes. The author is not quite sure but that Plate XXI. should have been substituted for Plate XXXII. for illustrating the convergence of uncorrected myopic orthophoric eyes.

Myopia with true Esophoria.—The brain center and muscle activity, for distant vision, in this condition, is the same as in emmetropic-esophoric eyes, and is illustrated in Plate

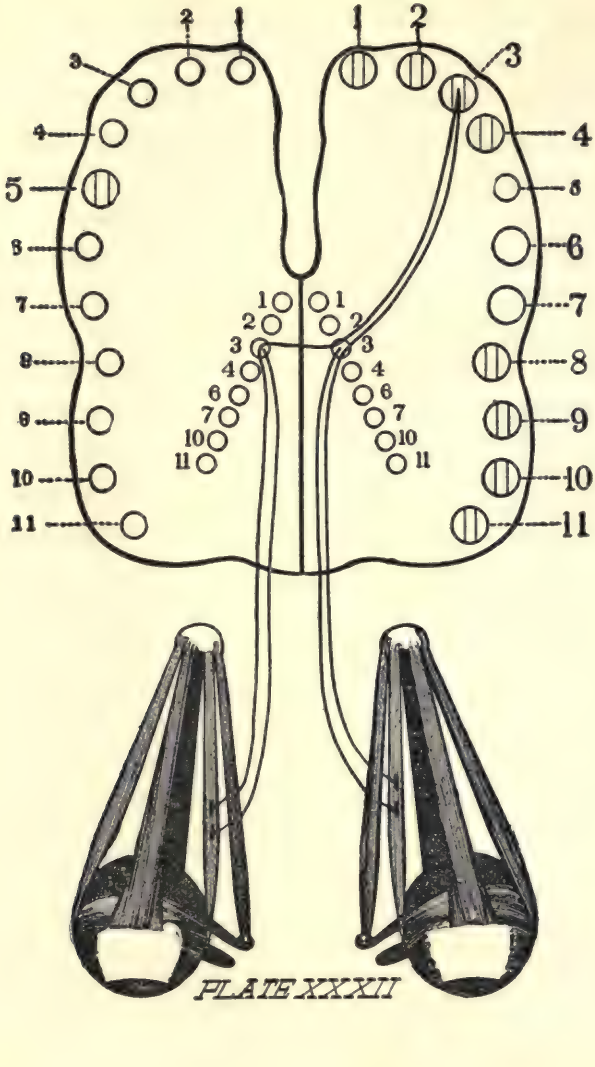

PLATE XXXII

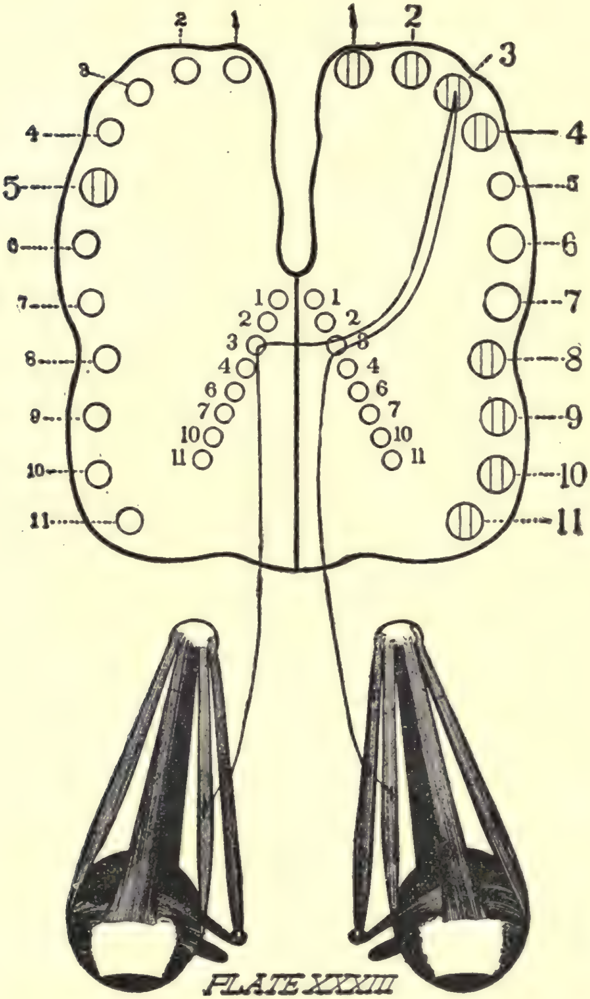

PLATE XXXIII

XVII. By reference to this plate, it will be seen that the excited brain centers are the right and left fourth basal, and that the muscles are the two externi. The accurate correction of the myopia will not modify, in the slightest, the esophoria for distance. The convergence of such eyes is more easily effected than if there had been orthophoria for distance, for the reason that the greater tonicity of the interni would effect a part of the convergence, leaving only a remainder to be accomplished by the right and left third basal centers. The greater the esophoria for distance, the less the demand that would be made on the right and left third basal centers in near work. Only a partial correction of the myopia should be given for near seeing, when there is esophoria for distance, for reason that the complete correction of the myopia would cure all the pseudo-exophoria, and there would be esophoria in the near as in the far. The convergence of uncorrected myopia of esophoric eyes is illustrated in Plate XXI.; that of partial correction is shown in Plate VIII., and that of a full correction in Plate XVIII. No lenses at all for near work would be preferable to fully correcting lenses, for the reason that over-work of the right and left third basal centers is better borne than excitation of the right and left fourth basal centers. The ideal lenses for the near use of myopic-esophoric eyes, are those that will give orthophoria in the near test. Such lenses allow

enough pseudo-exophoria to remain to neutralize the intrinsic esophoria.

Myopia with true Exophoria.—The excited brain centers and active muscles, when the gaze of myopic-exophoric eyes is direct and at infinity, are shown in Plate XXI. This Plate also shows that the right and left third basal centers are excited and the two interni are contracting to prevent diplopia of emmetropic-exophoric eyes. If it were possible for the third conjugate center to act independently of the tenth conjugate center, which is a matter for doubt, then the exophoria of both emmetropic and myopic eyes, whose gaze is direct and at infinity, might be counteracted by this (the third) conjugate center, for the contraction of each internus, under such a condition, would be the same as that of the other. This effort of brain center and muscles would be illustrated by Plate XXXIII. If the teaching concerning the distant vision of emmetropic-exophoric eyes, as illustrated in Plate XXI., is true, then the same teaching concerning the distant vision of myopic-exophoric eyes must also be true. The only alternative is the teaching of Plate XXXIII., and it would be applicable alike to the exophoria of both emmetropic and myopic eyes. Plate XXXIII. is introduced here, but is not indorsed.

The correction of myopia will sharpen vision, but will not alter the muscle relationship so long as the gaze is fixed on a distant object, therefore the right and left third basal cen-

ters and the two interni must do the same work whether the correcting lenses are worn or not. In the near use of uncorrected myopic eyes which have true exophoria, there is a greatly increased demand for activity on the part of the right and left third basal centers, for not only must the true exophoria be corrected by these centers, but also the pseudo-exophoria. The following case may be supposed, though often real: The myopia is 3-D and the true exophoria is 6°. In distant vision the right and left third basal centers must discharge enough neuricity to the interni to counteract the 6° of exophoria. In near vision there is still the 6° of true exophoria, and added to this there is, approximately, 6° of pseudo-exophoria, making twelve in all. Since all of this must be counteracted by the right and left third basal centers, it must appear that in near vision these centers have to do twice the work demanded of them in distant vision. Correcting the myopia, and thereby curing the pseudo-exophoria, leaves only the true exophoria to be counteracted by activity of the right and left third basal centers, when these eyes are engaged in near work. Plate XXI. illustrates the centers and muscles that are active in the near use of these supposed eyes, the myopia being uncorrected, it being only necessary to remember that the activity of these centers in distant vision is doubled in near vision. Plate XXII. illustrates the near use of this same pair of eyes, the myopia having been

fully corrected. The concave lenses have made these eyes emmetropic, but there remains unchanged the true exophoria. If an over-correction of the myopia has been given, if —6-D lenses have been given, when the myopia is only 3-D, all the pseudo-exophoria has been cured, and the true exophoria has been fully counteracted by the newly developed pseudo-esophoria. Under the influence of this over-correction the interni act only under the impulse sent them from the third conjugate center, in harmony with the activity of the tenth conjugate center and the ciliary muscles, as illustrated in Plate VIII., but the third and tenth conjugate centers are doing twice the work demanded of them in the convergence-accommodation of emmetropic eyes. An over-correction of myopia, when there is exophoria, is often attended by more comfort than a simple full correction. There appears to be no reason for this other than the fact that the over-correction relieves, in part or in whole, the right and left third basal centers in both distant and near vision, while a full correction leaves the work of correcting all the true exophoria, in both distant and near vision, to these basal centers. This experience, which is common, would show that the conjugate centers have greater power of endurance than the basal centers. As to the interni, they must do the same contracting, whether stimulated wholly by either the basal centers or the conjugate center, or in part by each of these centers. If these muscles do their

work better and more comfortably under the influence of the third conjugate center, than under the influence of the right and left third basal centers, then the exhaustion would appear to come from activity of the basal brain centers, and not from muscle contraction. To relieve the right and left third basal centers in the distant and near use of myopic-exophoric eyes, it is not best to give an over-correction of the myopia, because that involves the tenth and third conjugate centers in an excessive amount of work, which they might bear well for a time, but under which they must finally break down. Nor does the over-correction bring any rest to the interni. The rational treatment of such eyes is to cure all the pseudo-exophoria by fully correcting the myopia, demanding that the lenses shall be worn throughout all working hours, and cure by exercise or operations the true exophoria. This would bring to such eyes, in distant vision, the restfulness of brain centers and muscles shown in Plate VII.; and the near vision (convergence-accommodation) would be attended by normal activity of the tenth and third conjugate centers and the ciliary and internal recti muscles, illustrated in Plate VIII.

If it is possible for the third conjugate center to help the right and left third basal centers, independent of the tenth conjugate center, in converging myopic-exophoric eyes, the myopia being uncorrected, then Plate XXXII. would illustrate the activity of the third conjugate and the right

and left third basal centers, and the interni, in their work of converging such eyes. Even if this illustration were correct, it would not change the correct method of treatment of such cases, that is, fully correct the myopia and thus cure the pseudo-exophoria, which can exist only in the near use of the eyes; then by exercise or operations cure the true exophoria which exist in both far and near use of the eyes. How to do the one or the other is fully set forth in *Ophthalmic Myology*, in the chapter on exophoria.

HYPEROPIA.

Hyperopia and Orthophoria.—In hyperopia there is always a pseudo-esophoria in both distant and near seeing, the quantity of this pseudo error being about 2° for each 1-D of the hyperopia. All other muscle errors associated with hyperopia are true or intrinsic.

Plate XXXIV. represents hyperopic-orthophoric eyes and the conjugate and basal centers that are excited, and the muscles that must contract, in the interest of sharp seeing and binocular single vision. The object of fixation is at practical infinity and in line of intersection of the extended horizontal and median fixed planes of the head. The tenth conjugate center is excited, in order that the ciliary muscles may cause well defined images to be formed on the two retinas. There being lateral orthophoria, the visual axes would be properly related without any impulse being sent

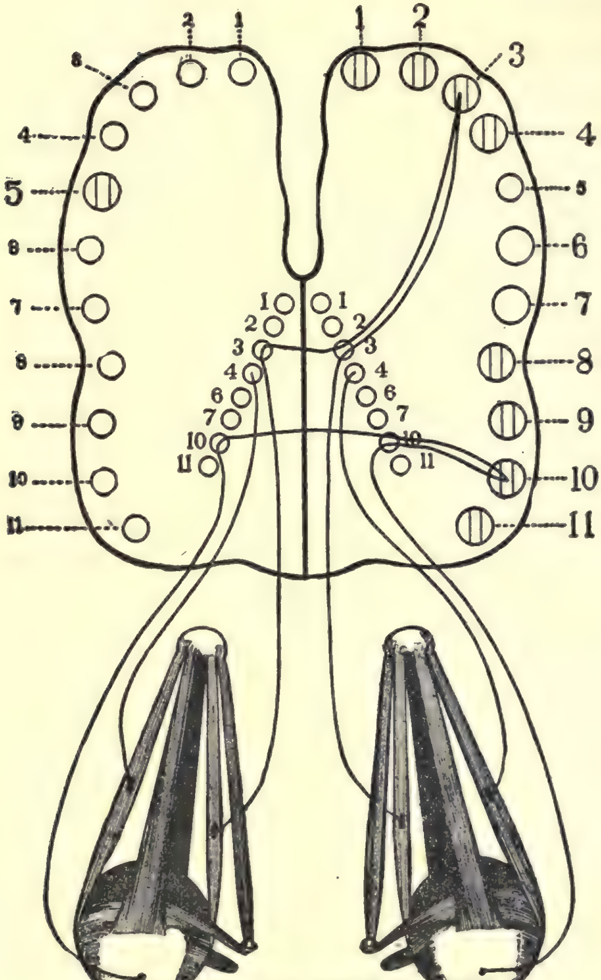

PLATE XXXIV

from either cortical or basal centers, but excitation of the tenth conjugate center would have associated with it excitation of the third conjugate center. This associated activity of the third conjugate center would make the interni contract, and this would cause the visual axes to cross between the object of fixation and the eyes, resulting in double vision, but for the fact that the fusion faculty of the mind calls into simultaneous action the right and the left fourth basal centers, in the interest of binocular single vision. These basal centers would send enough neuricity to their respective externi to make them contract sufficiently to prevent the contracting interni from crossing the visual axes too soon. Two conjugate and two basal centers must be forever actaive, and both ciliary muscles and the two internal and two external recti muscles must be in a continuous state of contraction, when hyperopic-orthophoric eyes are looking straight ahead into infinity. The brain and muscle work of such eyes, in distant vision, may be contrasted with the restfulness of both brain and muscles when eyes are emmetropic and orthophoric, by comparing Plates XXXIV. and VII.

That the esophoria shown in Plate XXXIV. is pseudo, and not true, is made evident by the fact that a correction of the hyperopia will cause the esophoria to disappear. It is probable that hyperopia causes symptoms, not so much because of excitation of the tenth and third conjugate cen-

ters, but because of the work that the right and the left fourth basal centers must do to prevent diplopia. Proof of this statement will appear in the study of hyperopic-exophoric eyes.

A full correction of the hyperopia shown in Plate XXXIV. relieves the tenth conjugate center of any necessity for action. This allows the third conjugate center to cease discharging neuricity to the interni, hence there can be no longer any need for activity of the right and left fourth basal centers. Simple convex lenses would bring to hyperopic-orthophoric eyes, in distant vision, the restfulness of brain centers and muscles of emmetropic-orthophoric eyes shown in Plate VII. Nothing more could be desired; nothing less should be done.

Plate XXXIV. not only shows what brain centers and muscles must be active in the distant vision of hyperopic-orthophoric eyes, but it also shows that the same centers and muscles must be active in near vision. Any work on the part of these centers, in distant seeing, is over-work, or strain, hence the near use of such eyes must also be attended by over-work, or strain. The convex lenses for the correction of the hyperopia makes near work easy, in that the right and left fourth basal centers will be entirely relieved and the tenth and third conjugate centers will have to do only normal work. So far as near work is concerned,

the correction of the hyperopia converts Plate XXXIV. into Plate VIII.

It will be observed that the same basal and conjugate centers are active in the distant and near vision of hyperopic-orthophoric eyes as are active in the near use of emmetropic,-esophoric eyes, for Plate XXXIV. is the same as Plate XVIII. The difference in the character of the work done cannot be shown in a plate. In each plate the work done by the two fourth basal centers and the two externi is abnormal work, or strain; in plate XVIII., the work of the tenth and third conjugate centers and the ciliary muscles and the interni is normal work, but in Plate XXXIV. the work of these conjugate centers is abnormal, and therefore is strain.

So long as there is any power to accommodate, no correction of hyperopia should be attempted without the aid of a cycloplegic.

Hyperopia and True Esophoria.—Plate XXXIV., used for illustrating hyperopic-orthophoric eyes, in both distant and near seeing, must also be used for showing the brain centers that are active and the muscles which are made to contract, in both the far and near seeing of hyperopic-esophoric eyes. The hyperopia being the same in the two cases, the tenth and third conjugate centers do no more in the one case than in the other, but in the hyperopic-esophoric case the right and left fourth basal centers are

doubly taxed—that is, they must send neuricity to the externi to counteract the pseudo-esophoria caused by the hyperopia, and they must also supply these muscles with the force necessary for counteracting the intrinsic esophoria. This excessive draft on the right and left fourth basal centers must be kept up in near vision as well as in far, therefore there is no rest during all the waking hours. If there is true esophoria 4°, and pseudo-esophoria 4°, the total to be counteracted by the basal centers is 8°. The correction of the hyperopia, by proper lenses, cures the 4° of pseudo-esophoria, but still leaves the burden of counteracting the 4° of true esophoria on the right and left fourth basal centers. This correction of the hyperopia converts Plate XXXIV. into XVIII., so far as distant vision is concerned, in which the only active centers are the right and left fourth basal. Even with the hyperopia corrected, the near use of these eyes would still be illustrated by Plate XXXIV., although now these basal centers must counteract only the true esophoria.

That it is the activity of the right and left fourth basal centers, and the consequent contraction of the externi, that produces the various symptoms of which such patients complain, and not the associated activity of the tenth and third conjugate centers, and the consequent contraction of the ciliary muscles and the internal recti, seems clear, in the light of the fact hat the same hyperopia associated with

4° of true exophoria, rarely causes any trouble at all. This latter condition furnishes only enough pseudo-esophoria to neutralize the true exophoria, hence no basal center is active, as shown in Plate XXXV. The result of treatment also points to the fact that the basal centers are the source of symptoms. A correction of the hyperopia associated with true esophoria brings great relief, although there is still left some work for the right and lefth fourth basal centers to do, in both far and near seeing. Correction of the hyperopia associated with exophoria, at once calls into action the right and left third basal centers, in both distant and near seeing, to counteract the true exophoria, and discomfort, before unknown, arises. In each of these cases the tenth and third conjugate centers have been relieved alike of the necessity for abnormal work, but in the former case half the burden has been removed from the right and left fourth basal centers, while in the latter a new demand on the right and left third basal centers has been created.

That hyperopia is one of the causes of esotropia is proved by the well known fact that a full correction of this focal error, soon after squint has manifested itself, will allow the eyes to swing straight again. That many cases of esotropia have ben caused by hyperopia alone may be doubted, though a high degree of this focal error might do so. If the lateral muscles, in a given case, are well balanced, each fourth basal center should be able to produce

8° of abduction. Every dioptre of hyperopia causes nearly 2° (1.8°) of pseudo-esophoria, hence 4 D. of hyperopia would cause 8° (7.2°) of pseudo-esophoria, which should be counteracted by normal externi, in the interest of binocular single vision. A much higher degree of hyperopia alone could cause an esotropia, for the resultant pseudo-esophoria would be greater than the fourth basal centers and their externi can counteract. Usually the fundamental cause of esotropia is true esophoria; but it would take 8° or more of this error, unaided, to cause internal squint. In the greater number of cases true esophoria and pseudo-esophoria constitute the twin causes of esotropia. Either one of these errors alone might be counteracted by the action of the right and left fourth basal centers on their respective externi. The task of counteraction, except in rare cases, is always undertaken by the fusion faculty of the mind, and often the work is maintained throughout life; but not infrequently the fourth basal centers become exhausted; and, refusing to respond longer, the interni are allowed to cross the visual axes. After an interval of rest these centers sometimes reassert themselves, and, for a short period, straighten the eyes again, to once more fail after another period of exhaustive work. Finally the squint becomes fixed, and thereafter the fourth basal centers remain as inactive as in orthophoria. Usually this occurs so early in life (between the ages of one and three

years) that the power of mental suppression may be acquired. Thus the patient loses the power of binocular vision, but he gains in comfort—not that the conjugate centers have less to do, but because the basal centers have lapsed into rest. So long as esotropia is comitant there is comparative comfort; but there is also disfigurement.

The treatment of hyperopic-esophoric eyes should be so directed as to bring complete rest to the right and left fourth basal centers, regardless of the point of view; it should also give rest to the tenth and third conjugate centers, and their respective muscles, in distant vision, so that near work may be accomplished by only a normal expenditure of nerve force and muscle energy. First of all, the hyperopia should be corrected, while the eyes are under the influence of a cycloplegic, for in no other way can it be accurately done. The convex lenses at once accomplish the work of completely relieving the tenth and third conjugate centers, and the ciliary muscles and the internal recti, from the necessity of doing any abnormal work. So far as these centers and muscles are concerned, the lenses will give the same rest in distant vision, illustrated in Plate VII. Only the pseudo-esophoria, in both far and near vision, can be cured by the convex lenses; hence these lenses can relieve, only partially, the right and left fourth basal centers, and their respective external recti. The correcting lenses would leave such eyes, so far as distant vision is concerned, in the condition illus-

trated in Plate XVII., in which the right and left fourth basal centers must force the weak externi to counteract the excesive tonicity of the interni. That the cure may be complete, the weak externi must be developed by rhythmic exercise, or they must be strengthened by the shortening operation; or the tonicity of the interni must be reduced by partial tenotomy. The aim of either means is to make the tonicity of the externi equal the tonicity of the interni. No part of the pseudo-esophoria can be corrected by any kind of exercise, and certainly no part of it should ever be corrected by any kind of operation. Lenses for the hyperopia and pseudo-esophoria, and exercise or operations for the true esophoria, will convert hyperopic-esophoric eyes into emmetropic-orthophoric eyes. The restfulness of brain centers and muscles, in distant vision, resulting from the treatment outlined above, of hyperopic-esophoric eyes, is correctly shown in Plate VII. The change wrought can be easily understood by comparing Plates XXXIV. and VII. The near use of eyes thus fully corrected is illustrated in Plate VIII. If only the hyperopia and the pseudo-esophoria have been corrected by the lenses, the true esophoria remaining, the near use of these eyes would be shown in Plate XVIII. In Plates VIII. and XVIII., the tenth and third conjugate centers are doing precisely the same work, but in the former plate the right and left fourth basal cen-

ters are at rest, while in the latter plate these two centers are excited that the true esophoria may be counteracted.

While true esophoria cannot be lessened by any lens, so far as distant vision is concerned, a pseudo-exophoria in the near may be created by the wearing of presbyopic lenses, or lenses that over-correct the hyperopia. The presbyopic lenses lessen the demand on the tenth conjugate center, and an associated smaller demand is made on the third conjugate center. This allows the convergence to be effected largely by tonicity, and the right and left fourth basal centers are relieved correspondingly. But to give presbyopic lenses while one is yet young is not the best thing to do. It would be justified only by the refusal of the patient to submit to the exercise or operative treatment of the true esophoria.

Whenever the esophoria of hyperopic eyes has been converted into an esotropia, the correction of the hyperopia should not be delayed even though the patient might be only two years old. The eyes have crossed because the right and left fourth basal centers, exhausted by overwork, have given up the task of supplying the external recti with the neuricity necessary for counteracting the pseudo- and intrinsic esophoria. Either one of these errors existing alone might have been counteracted by the fourth basal centers acting on the externi, but the sum of the two errors caused so great demands on these centers and their muscles, in the

interest of binocular single vision, that it was only a question of a short time until they would fail to respond. Doubtless the power of mental suppression of the image in the crossed eye had been acquired previously; for the mind has two methods of preventing diplopia: one, the fusion of images by the exercise of the fusion faculty on basal centers, when there is abnormal adjustment; the other, mental suppresion of one image when the two cannot be fused.

The power to suppress entirely and continuously the macular image in one eye can be acquired only in early years, and then only because the two maculas must lose their proper relationship. The development of the mental suppression makes it easy for the fusion faculty to lose its control over all basal centers. This control being lost, all the basal centers lapse into a state of restfulness as complete as if the two eyes were orthophoric and emmetropic. Each cortical, or conjugate, center continues to discharge neuricity to its two muscles, just as it did before the eyes crossed, and just as it does when there is orthophoria, hence the two eyes, although crossed, move comitantly.

Every attempt to re-establish binocular single vision, without bringing discomfort to the patient, should aim at a cure of both the pseudo-esophoria and the true esophoria. The amblyoscope, used early and persistently, a fight against mental suppression, only helps the fusion faculty to maintain its mastery over the right and left fourth basal

centers; but this would be like forcing, with a whip, the weaker horse of a pair to draw its part of a heavy load. Fusion is always effective when the maculas are properly related, whether by muscle tonicity or muscle contractility. To regulate the tonicity of muscles is the way to get easy fusion of images. The pseudo-esophoria corrected by convex lenses, and the true esophoria cured by operations, gives the best chance for easy fusion, and the only chance for comfortable binocular single vision. The amblyoscope, as used by Worth and others who follow him, is but a means of awakening the mind to the fact that it has two eyes which it may use. The time to use this agent is after the hyperopia has been corrected, when the fourth basal centers may be made to take up the work of counteracting only the true esophoria, the pseudo-esophoria having already been cured. After a partial recovery from the mental blindness, the esophoria should be corrected so that, ever after, binocular single vision may be maintained without activity of basal centers, and without abnormal action of ocular muscles. For a fuller study of esotropia the reader is again referred to *Ophthalmic Myology.*

Hyperopia and Exophoria.—Hyperopia often exists in cases in which the externi are intrinsically stronger than the interni, but, notwithstanding, this hyperopia is the cause of pseudo-esophoria. Plate XXXV. represents such a pair of eyes engaged in either far or near seeing, the

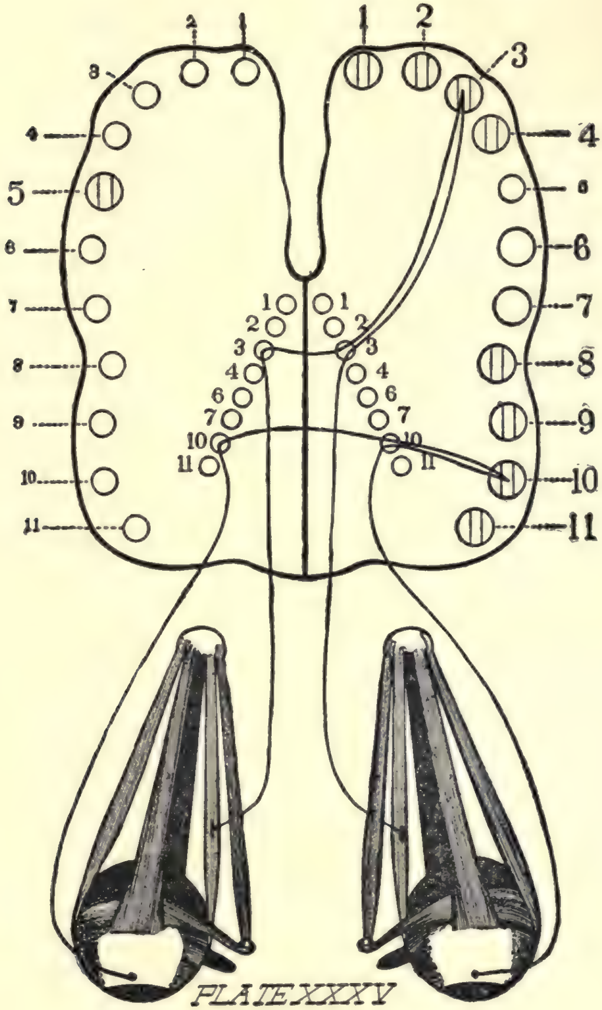

PLATE XXXV

point of fixation being on the line of intersection of the extended median and horizontal planes of the head. Perfect images of an object, either in the distance or near by, can be formed on the retinas only as a result of excitation of the tenth conjugate center. There must be associated activity of the third conjugate center and consequent contraction of the interni. This activity of the interni, excited by the third conjugate center, counteracts, in part or wholly, the true exophoria, thus relieving the right and left third basal centers of the necessity of counteracting this error. If, in a given case, there is exophoria 4°, and hyperopia 2 D, the pseudo-esophoria will be 4°, the latter counteracting the former. The association of hyperopia with exophroia is a fairly comfortable condition, as compared with the association of emmetropia with exophoria; and this is explainable only on the ground that, in the former, only conjugate centers are active, while in the latter basal centers must do the counteracting of the exophoria. A correction of the hyperopia of eyes truly exophoric converts Plate XXXV. into Plates XXI. and XXII., in each of which the right and left third basal centers are represented as actively counteracting true exophoria. Plate XXI. represents the eyes as looking into practical infinity, the only active brain centers being the right and left third basal, and the only contracting muscles, the two interni. Plate XXII. represents the eyes engaged in near work, the tenth

and third conjugate centers doing normal work, while the right and left third basal centers are combatting the exophoria.

The treatment of hyperopic-exophoric eyes should be directed, first, towards the correction of the exophoria, and should be either operative, or by exercise of the interni. If the muscles have been subjected to operations—partial tenotomies of the externi of shortenings of the interni—then a full correction of the hyperopia should be given, thus converting the condition shown in Plate XXXV. into the condition shown in Plate VII. If the treatment of the exophoria is by exrcise, as the interni gain in tone, a part of the hyperopia should be corrected; and from time to time, as the work of developing the interni goes on, still stronger lenses should be given, finally attaining the point of full correction only when there is no longer any exophoria. To correct the hyperopia and ignore the exophoria will bring discomfort to the patient whenever the correcting lenses are worn.

Every error of refraction should be carefully and accurately studied while the eyes are under the influence of a mydriatic, or, more correctly speaking, a cycloplegic, unless advancing years have already robbed the ciliary muscles of their power. Before the cycloplegic is used the tonicity tests of all the extrinsic ocular muscles should be made and recorded; but only the lateral recti would respond differ-

ently after the eyes have gone under the influence of the drug. No tonicity test of the lateral recti can be relied upon if made while the eyes are under the influence of a cycloplegic. If, in the tonicity test of the lateral muscles, there is esophoria of 4°, it cannot be known whether it is pseudo- or true until the refraction has been studied. If the eyes prove to be emmetropic, then the whole of the error is intrinsic, and the same is true if there is myopia of any quantity; but, if the eyes are hyperopic, the esophoria shown is the sum of the pseudo- and intrinsic errors, if not entirely pseudo. If the hyperopia is 2 D, the 4° of esophoria is, practically, all pseudo-esophoria. Every pair of convex spherical lenses given either cures a pseudo-esophoria, in both the far and near, or causes a pseudo-exophoria in the near; every pair of concave lenses given either cures an existing pseudo-exophoria in the near or causes a pseudo-esophoria in both far and near. Hyperopia should be fully corrected for both distant and near seeing only when the lateral muscles are well balanced or when there is intrinsic esophoria; an over-correction of hyperopia, in the near, should never be made unless there is intrinsic esophoria. When there is true exophoria, hyperopia should not be corrected, or, at most, only a partial correction should be given.

Regardless of the state of the lateral muscles, myopia should be fully corrected for distant seeing; and a full cor-

rection should be worn in near work, also, when there is perfect balance of the lateral recti muscles, or when there is true exophoria. No correction, or, at most, only a partial correction, should be worn in near work, when there is true esophoria. In true exophoria an over-correction of myopia often gives comfort to the wearer, for all distances.

To prescribe spherical lenses without a knowledge of the condition of the lateral recti muscles should be condemned.

CHAPTER IV.

COMPENSATING HETEROTROPIA.

Compensating heterotropia is an actual turning or torsioning of one or both eyes, in order that there may be binocular single vision. Whatever may be the form of this error, the muscle that does the turning or torting is made to do so by the action of the fusion faculty of the mind on the basal center with which it is connected. The work done by both basal center and muscle to effect this turning is the same that is done in heterophoria to prevent a turning; and, in each condition, the aim is to prevent diplopia. Compensating heterotropia may be excited by either natural or artificial conditions; but, whether natural or artificial, the condition is such as would produce diplopia, if not corrected.

NATURAL CAUSES.

Anisometropia.—Unequal hyperopia or myopia of the two eyes, or hyperopia of one eye and myopia of the other, must cause compensating heterotropia, whenever the eyes are rotated from the primary, to any secondary, position.

The eye that has the greatest refractive power, when looking at a rectangle, will have the larger image on its retina. This is shown in Figure 6, in which the rectangle *a b c d* is seen by the eye with less refractive power, while the eye of greater refraction sees the same rectangular figure

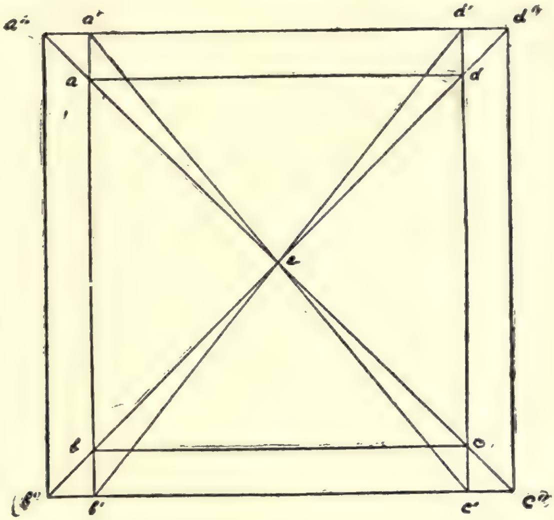

Fig. 6.

larger, as shown by rectangle a'' b'' c'' d''. If the head is in the primary position, and the center, *e,* of the rectangle is the point of fixation, there is no need for compensating contraction of any one muscle of an orthophoric set. If the eyes are to be verted, so as to fix any point

on the periphery of the rectangle, the visual axis of the eye, with the smaller image, could not reach this point in harmony with its fellow eye, under the influence of the volitional center, or centers, excited; for the arc of rotation of this eye is smaller than the arc that must be described by the visual axis of the eye with the greater refraction. To move in harmony, the latter eye must rotate faster than the former, and this can be done only by means of activity of the proper basal center. This can be better understood by again glancing at Figure 6. If the second point of view is the upper right hand corner of the rectangle, one visual axis must move from *e* to *d*, and the other must move from *e* to *d''*. The eye (right) that has the less refraction will be rotated, so that the image *d* may fall on its macula. This is accomplished by volition acting on the first, fourth and eighth conjugate centers, causing them to discharge neuricity to the superior and external recti and the superior oblique. The same centers, at the same moment, will discharge an equal quantity of neuricity to the superior and internal recti and inferior oblique of the left eye—the one with greater refraction. Thus stimulated, the visual axis would move with the same speed and to the same extent as the axis of the other eye. When the image of the corner of the rectangle falls on the macula of the right eye, the image in the left eye has not yet reached its macula, hence there would be diplopia. To prevent the diplopia supplemental

neuricity is sent by the left first, third and seventh basal centers, to the superior and internal recti, and inferior oblique, respectively, so that the left visual axis may reach *d″* at the same moment that the right visual axis reaches *d*. The three volitional centers act from the beginning to the end of the oblique right version, and the same is true of the three left basal centers. In such a case the basal centers get no rest except when the eyes are in their primary positions.

In direct right and left version of eyes of unequal refraction, only one basal center would be excited at a time; in superversion, two basal centers would be excited, and the same would be true of subversion.

In anisometropia the basal centers should be relieved of the work required of them. This can be done by the full correction of the error found in each eye. For all practical purposes the lenses would make the two images equal in size, therefore there would be no further need for activity of any basal center, or abnormal contraction of any ocular muscle.

In eyes of unequal refraction, the ciliary muscle, which has to do the most work, must receive supplemental neuricity from its tenth basal center. Full correction of the error in each eye would relieve this basal center also.

"It is more necessary to correct unequal refraction,

though the errors be not great, than it is to correct greater errors that are equal in the two eyes."

Displaced Anterior Pole.—If, in one or both eyes, the corneal center and the anterior pole do not coincide, there must be compensating heterotropia. (Displacement of the macula and displacement of the anterior pole are one and the same thing.) If the anterior pole is central in one cornea and is displaced nasal-ward in the other, there must be a compensating exotropia; if it is displaced temple-ward, there must be a compensating esotropia; if displaced upward, there must be a compensating catatropia; and if displaced downward, there must be a compensating hypertropia. When the anterior pole is displaced nasal-ward, which can be shown by the reflected image of the white-bordered disc of the opthalmometer, if the tonicity test does not show esophoria, it is because there is an excess of tonicity of the externus. In such a case there is a tonicity exotropia, making unnecessary a compensating contractile exotropia.

If one eye is placed lower in its orbit than its fellow eye, there must be a compensating hypertropia. The same is true when the head is inclined to one side.

The vertical and lateral heterotropias caused by the displaced anterior poles are best treated by prisms in positions of rest; that is, if the anterior pole is nasal-ward, the base of the prism should be out; if temple-ward, the base

should be in; if up, the base should be down; and if down, the base should be up. It must be remembered that the guide, as to the use of the prism in these cases, is the tonicity test of the muscles; for an eye whose anterior pole is nasal-ward, may have an externus with enough excess of tone to properly relate the eyes without demand on the fourth basal center. Indeed, the externi may be so much stronger than the interni as to make such eyes exophoric, and in such a case the third, and not the fourth, basal center must be active. The heterophorias of eyes with decentered corneas must be treated as if no decentration existed.

Eyes whose anterior poles are several degrees nasal-ward from the corneal center, have the appearance of slight external squint, and *vice versa.*

The compensating hypertropia caused by one orbit being lower than its fellow, should be treated with a prism, base up, provided the tonicity test shows cataphoria. The lower eye could have a superior rectus possessed of so much tonicity that the test would show hyperphoria.

The object to be accomplished by a prism in any form of compensating heterotropia, is to quiet a basal center and relieve the orthophoric eye from the necessity of turning; the object of the prism in heterophoria is to quiet a basal center and to allow the heterophoric eye to turn into the position of tonicity of its muscles. In both classes of cases

basal centers are placed at rest by the prisms, and binocular single vision is maintained.

In compensating vertical heterotropia a prism may be placed base up before the lower eye or base down before the higher eye, or the two may be given; but in vertical heterophoria it is always better to use only the prism base down before the hyperphoric eye, to make it easier for the superior oblique muscle to keep the vertical axis parallel with the median plane of the head.

Compensating Cyclotropia.—It is now universally agreed that, in astigmatism, every line not in the plane of the meridian of either greatest or least curvature, has its image displaced towards the meridian of greatest curvature. This displacement of the image of a line makes it impossible for the line and the image to lie in the same plane.

In hyperopic astigmatism, images formed between the two principal meridians, are always displaced towards the meridian of greatest curvature. This displacement of the image of a line makes it impossible for the line and the image to lie in the same plane. In non-astigmatic eyes the line and its image are always in the same plane; and the same is true of the line that lies in the plane of either of the two principal meridians of an astigmatic eye, but of no other line.

In hyperopic astigmatism, images formed between the two principal meridians are always displaced towards the

best meridian; in myopic astigmatism, towards the worst meridian; and in mixed astigmatism, towards the myopic meridian. In symmetric astigmatism—that is, when the planes of the meridians of greatest curvature are parallel, or, if horizontal, they both lie in the same plane, the two immages of a single object will always fall on corresponding retinal parts, whether displaced or not, hence can be fused, while both vertical axes are still parallel with the median plane of the head.

Parallel and equal astigmatism of orthophoric eyes makes no demand for compensating contraction of any ocular muscle, for, without this, all images are perfectly fused. The heterophorias bear the same relationship to hyperopic astigmatic eyes that they do to hyperopic eyes; and they have the same relationship with myopic astigmatic eyes that they have with myopic eyes.

In non-symmetric oblique astigmatism, unless the best meridian of one eye and the worst meridian of the other are parallel, one image, if not both, of every object, is displaced on the retina. If one image of an object, as a line, is not displaced on one retina and the other image is displaced, they fall on non-corresponding parts of the retinas, so long as the vertical axes remain parallel with each other. This would cause diplopia. If, in such eyes, both images are displaced, they cannot fall on corresponding retinal parts, hence there would be diplopia, if the vertical axes

remained parallel. Nature has made provision against this diplopia.

The displacement of images by astigmatic eyes can be best understood by a study of the images of a horizontal object, as an arrow. Figure 7 shows the two images on the retinas of astigmatic eyes whose meridians of greatest curvature are vertical. (The images would be similarly related if the eyes were non-astigmatic; and the same would be true of astigmatic eyes with the meridians of greatest curvature horizontal.) These two images lie on corresponding meridians, and, therefore, would be fused without the aid of any basal center, the eyes being orthophoric. If the arrow were held in any oblique position, the images would fall on corresponding parts of the two eyes, for the images in the two eyes would be displaced in the same direction and to the same extent, hence would be fused without the aid of a basal center. Since the fusion faculty of the mind acts only when there is a condition that would cause diplopia, this faculty, and the basal centers under its control, are all at perfect rest, regardless of the position, in space, of the object of fixation, whenever orthophoric eyes have equal astigmatism, the meridians of greatest curvature being vertical. The same is true of astigmatic eyes whose meridians of greatest curvature are horizontal.

Figure 8 represents a pair of astigmatic orthophoric eyes in which the meridian of greatest curvature in each

eye is at 135°. On each retina the image of the arrow is displaced towards the meridian of greatest curvature, and to the same extent. As shown in the cut, each image rests on meridian 170°. These meridians correspond, therefore the images must be fused; and that, too, without having caused the fusion faculty to excite a single basal center. With the images resting, as they do, on retinal meridians

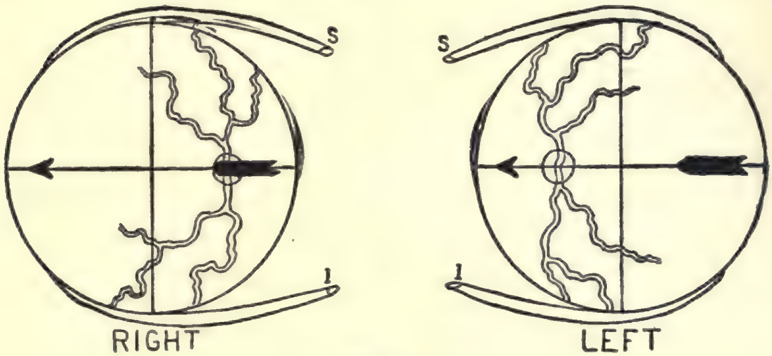

Fig. 7.

170°, the horizontal arrow will appear to dip 10° to the left; for the only line that can appear to be horizontal is the one whose images rest on meridians 180°, when the head is erect. That the eyes shown in Figure 8 may see a line as if horizontal, the line itself would have to be inclined 10° to the right. No brain center need act in the interest of fusion, for there is no condition to cause diplopia; but correct orientation with such eyes is impossible.

A correction of this symmetric oblique astigmatism relieves no basal center, for none has been active; but the correcting lenses so change the images that a horizontal line has horizontal images; a vertical line, vertical images; and an oblique line, images of the same obliquity. The correction of symmetric oblique astigmatism is largely in the interest of sharp vision and correct orientation; but, as will

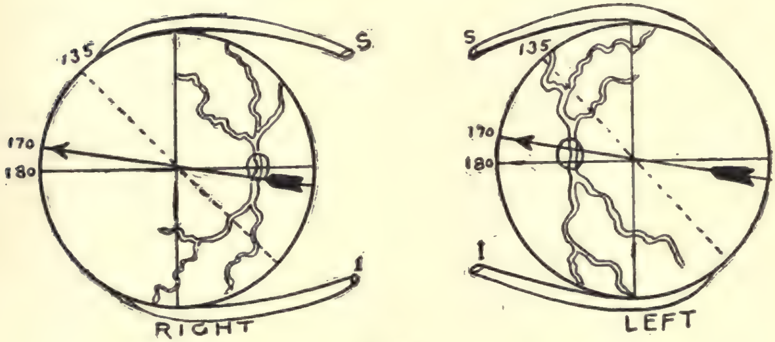

Fig. 8.

be shown later, such correction relieves brain centers connected with the ciliary muscles.

Figure 9 represents a pair of astigmatic orthophoric eyes, the meridian of greatest curvature of the left eye being vertical and that of the right eye at 135°. The image of the horizontal arrow, in the left eye, will lie on meridian 180°; but the image in the other eye, being displaced towards the meridian of the greatest curvature, will lie on

meridian 170°. Since these two meridians do not correspond, there would be diplopia, if the vertical axes were allowed to remain parallel. To prevent the diplopia, the fusion faculty would cause the right sixth basal center to send neuricity to the right superior oblique, so that meridian 180° shall be brought under the displaced image. The fusion is effected by allowing the vertical axis of the

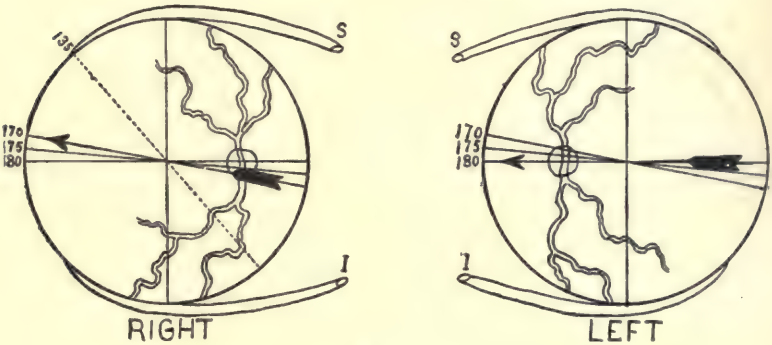

Fig. 9.

left eye to remain parallel with the median plane of the head, while the vertical axis of the right has been inclined 10° towards the median plane, this inclination being accomplished by contraction of the right superior oblique, under the stimulus of neuricity sent to it by the right sixth basal center. Correction of the astigmatism, by the proper cylinders, will make these eyes, to all intents and purposes, emmetropic, hence the two images of every external object

would fall on corresponding retinal parts, thus putting at rest the fusion faculty, the right sixth basal center and the right superior oblique muscle.

Figure 10 represents a pair of astigmatic orthophoric eyes, the meridian of greatest curvature of the left being at 90° and that of the right at 45°. The image of the horizontal arrow, in the left eye, lies on meridian 180°;

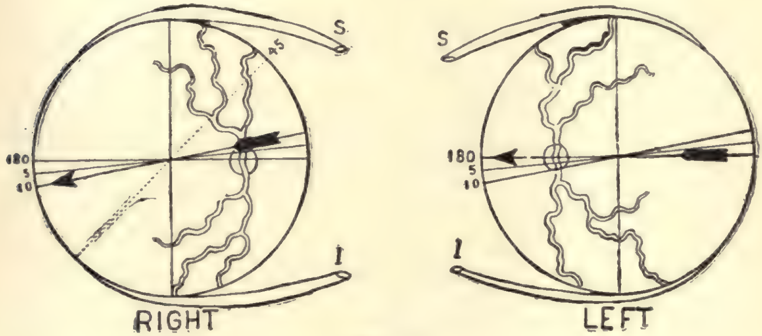

Fig. 10.

but the image in the right eye has been displaced so that it lies on meridian 10°. Since these meridians do not correspond, there must be diplopia, unless the fusion faculty, through the proper basal center and muscle, counteracts it. The fusion faculty, this time, causes the right seventh basal center to send neuricity to the right inferior oblique, the contraction of which so torts the eye as to bring meridian 180° under the displaced image. In effecting fusion, the

vertical axis of the left eye has been allowed to remain parallel with the median plane of the head, while the vertical axis of the right eye has been inclined 10° from this plane. A correction of the astigmatism harmonizes images, and allows the fusion faculty, the right seventh basal center, and the inferior oblique, to lapse into restfulness.

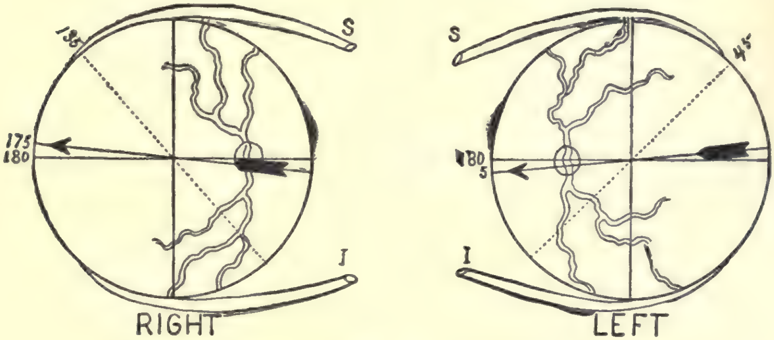

Fig. 11.

Figure 11 represents a pair of astigmatic orthophoric eyes, the meridian of greatest curvature of the right eye being at 135° and that of the left at 45°. Both images of the horizontal arrow are displaced and in opposite directions, but in obedience to the same law. The image, in the right eye, lies on meridian 175°, and that in the left eye on meridian 5°. These two meridians do not correspond, hence there must be diplopia, if the vertical axes are allowed

to remain parallel. Plate XXXVI. shows how the fusion faculty causes the right and left sixth basal centers to send neuricity to the two superior obliques, so that they may tort the two eyes, and thus bring the two horizontal meridians under the displaced images. The vertical axis of each eye has been made to incline 5° towards the median plane of the head, but this torting, or compensating cyclotropia, has

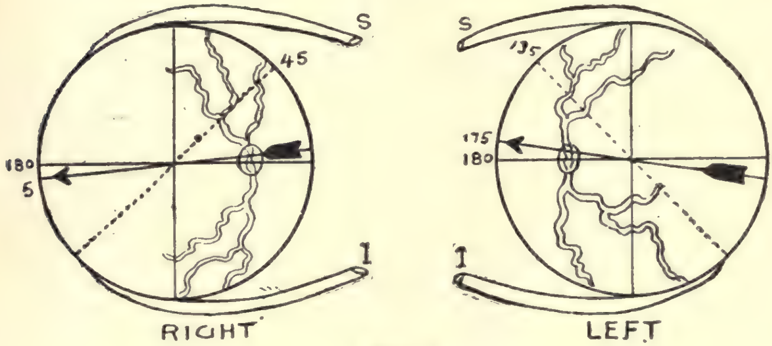

Fig. 12.

prevented diplopia. If the compensating cyclotropia must be the same in each eye, it could be effected by a discharge of neuricity from the sixth conjugate center, and if so, Plate XXVIII. would show the brain and muscle activity that would effect it. It is probably true that the sixth conjugate center acts only with the second conjugate center, to prevent a plus cyclotropia rather than cause a compensating minus cyclotropia. A correction of the astigmatism

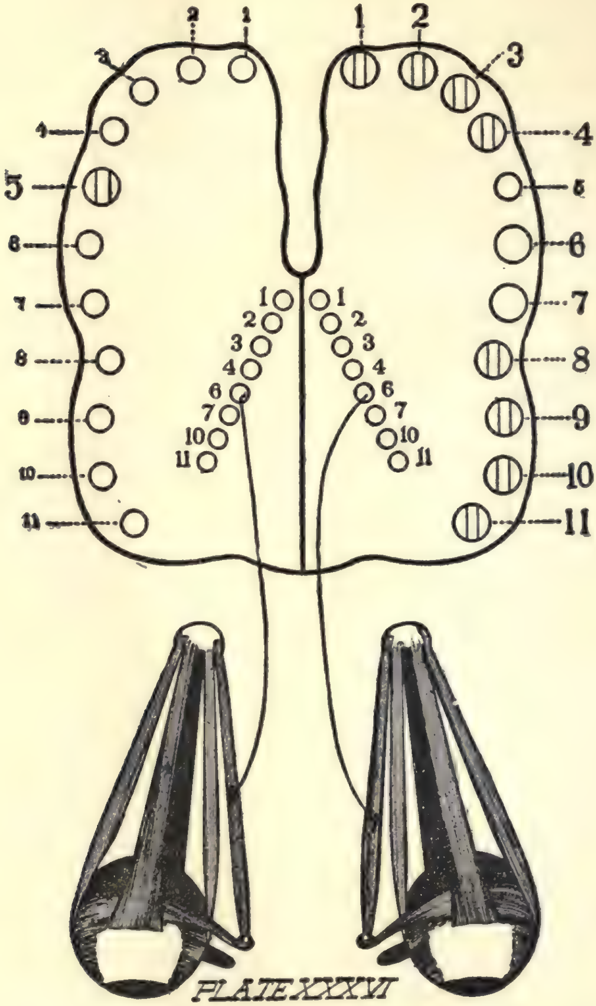

PLATE XXXVI

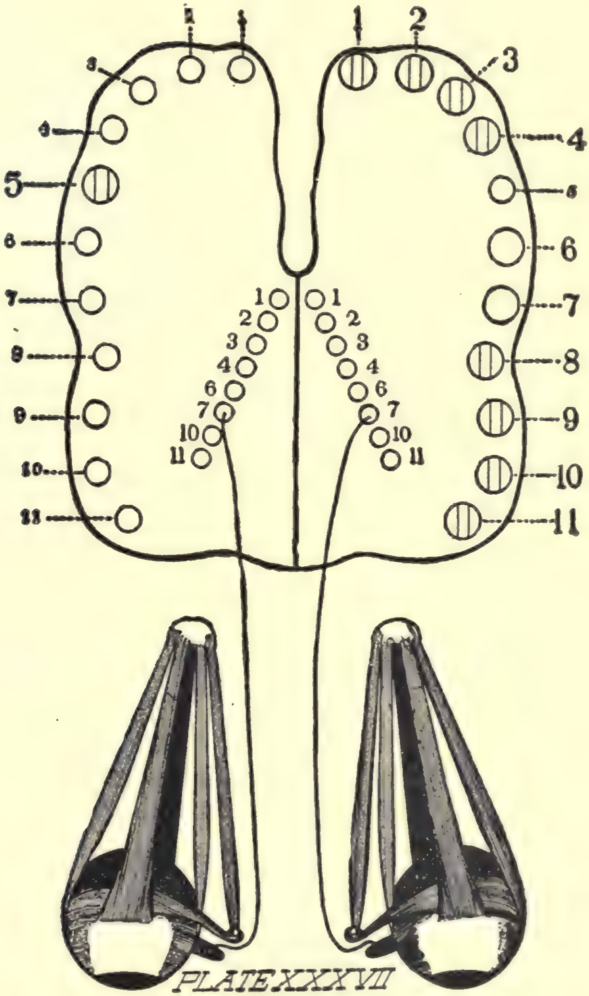
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PLATE XXXVII

will harmonize all images, and thus allow the fusion faculty, the right and left sixth basal centers, and the two superior obliques, to assume the restful state normal to each.

Figure 12 represents a pair of astigmatic orthophoric eyes, the meridian of greatest curvature of the right at 45°, and that of the left at 135°. The image of the horizontal arrow in the right eye is on meridian 5°, and that in the left eye on meridian 175°. These meridians do not correspond, hence there must be diplopia, if the vertical axes are allowed to remain parallel. The prevent the diplopia, the fusion faculty causes the right and left seventh basal centers to send neuricity to the two inferior obliques. These muscles, responding to the stimulus received, tort the two eyes out-ward, so that the normally horizontal meridian of each eye may be brought under the displaced image, and thus make fusion possible. This action of basal centers and muscles is illustrated in Plate XXXVII.

Since the displacement of the images is equal in the two eyes shown in Fig. 12, it would be possible for fusion to be effected by neuricity sent from the seventh conjugate center, provided this center ever acts independently of the first conjugat center. Such activity of this center, if it were possible for it to effect a compensating plus cyclotropia, would be illustrated in Plate XXX. If it is not capable of producing a plus cyclotropia, it cannot counteract a minus cyclophoria, hence Plate XXX. would have

to be substituted by Plate XXXVII. Since the seventh conjugate center could not cause the inferior obliques to fuse the two images, whenever one image is more displaced than the other, though in opposite directions, it is reasonable to conclude that this center never undertakes such work, leaving the fusion of such images entirely to the right and left seventh basal centers.

Symmetric astigmatism means astigmatism equal in the two eyes, with the meridians of greatest curvature parallel; non-symmetric astigmatism means unequal astigmatism in the two, or that the meridians of greatest curvature are not at the same angle; or it means both of these.

So far this study has shown that symmetric astigmatism does not call on the fusion faculty to excite any one of the four basal centers, connected with the oblique muscles, into fusional activity; that non-symmetric oblique astigmatism always makes demands on one or two of the four basal centers connected with the obliques; and that the two kinds of astigmatism differ only in that the former makes no demands on either of the four fusional centers connected with the obliques, while the latter keeps one, if not two, of these centers constantly at work in the interest of fusion. For lack of a better name, this work has been called compensating cyclotropia.

Plates XXXVIII. and XXXIX. are introduced here to impress still further the image changes caused by non-sym-

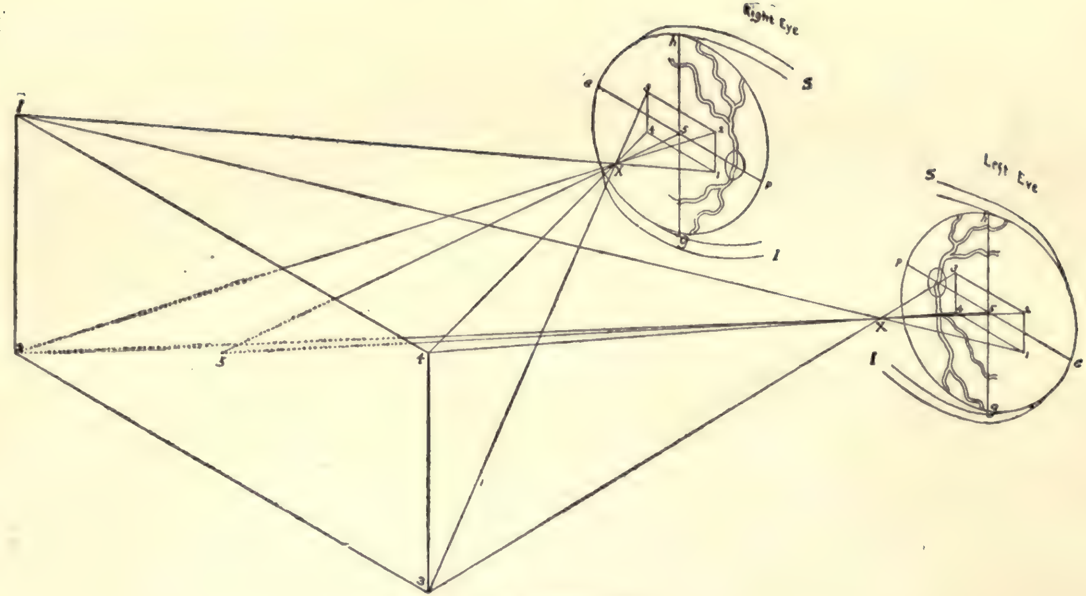

PLATE XXXVIII.

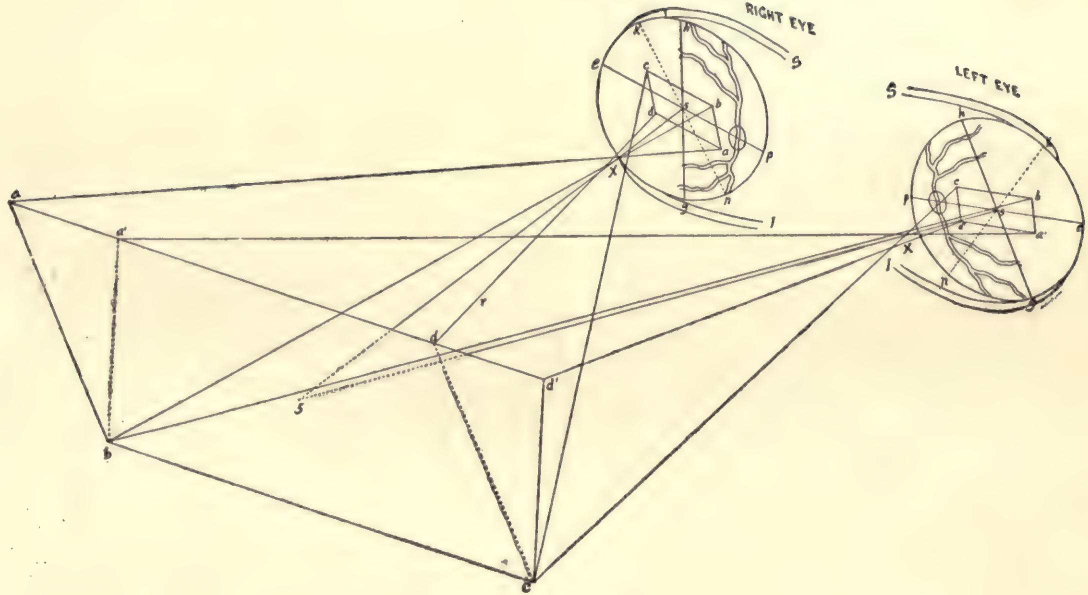

PLATE XXXIX.

metric oblique astigmatism; and, to illustrate the torsioning that must take place, in the latter, in order that there may be fusion, though imperfect. Another important lesson that Plate XXXIX. teaches is that, when both vertical and horizontal lines compose a figure (the rectangle) the mind effects, by preference, the fusion of the horizontal lines. This may have some relationship with the fact that the fusion field of the retina is greater horizontally than vertically.

Plate XXXVIII. represents a pair of symmetric astigmatic eyes, the meridians of greatest curvature being either vertical or horizontal. The object of view is a rectangle, the upper and lower borders being horizontal, and in each eye the image is also a rectangle. Either eye alone, or the two together, would see the figure as it is, a rectangle. Looking closely at the image it will be seen that the upper and lower borders of the images, corresponding, respectively, with the lower and upper borders of the figure, are parallel with the horizontal retinal meridians; and that the right and left borders of the images, corresponding respectively with the left and right borders of the figure, are parallel with the vertical retinal meridians. The lines connecting parts of the images and the object that correspond, represent lines of direction, all of which cross at a common point, the center of retinal curvature; for each line of direction, in eyes whose vertical axes are parallel with the

median plane of the head, is a radius of retinal curvature prolonged. Each eye sees the rectangle as it is and where it is. That these eyes have not been torted, in the interest of fusion, is shown by the fact that the two horizontal meridians lie in a common plane, and the two vertical meridians are perfectly parallel.

If the rectangular figure were held obliquely in front of these eyes, the two images would be alike, but each would be a non-rectangular parallelogram. All the lines of direction would cross at a common point, and each two lines would intersect at a common corner of the figure, but the lines forming the figure would not make it apepar as a rectangle, but as a non-rectangualar parallelogram. Continuing to rotate the rectangular figure, the images as continually change in shape, until, the sides becoming vertical and the ends horizontal, the images are again rectangular, and the figure is seen once more as a rectangle. Whatever may be the position of the figure before these eyes, and however it may appear distorted, the fusion has been effected without excitation of a single basal center, or the contraction of a single muscle.

The same rectangle held before non-astigmatic eyes, in any position, would have formed on each retina a rectangular image, and the figure in all positions would appear as a rectangle. A correction of the astigmatism makes the eyes, shown in Plate XXXVIII., emmetropic; and the rec-

tangular figure, held in an oblique position, would be seen as a perfect rectangle, just as perfect as the one shown in the plate. There would be no metamorphosia to annoy the wearer of the correcting lenses. Metamorphopsia is not caused by the wearing of cylinders that correct symmetric astigmatism, whether the meridians of greatest curvature are vertical, horizontal or oblique. The reason for the absence of the metamorphopsia, in these cases, is: Not one of the four basal centers, connected with the four obliques, has ever been excited in the interest of fusion, hence not one of these centers has formed a habit that it will take time to break. In monocular vision, basal centers that have been active in binocular vision, lapse at once into a state of rest; but an attempt to use the two eyes at once arouses these centers into action. The condition demanding activity of these centers may have been removed, but, notwithstanding, the old habit of action will assert itself for a time. This will be better understood in the study of the next plate.

Plate XXXIX. represents a pair of non-symmetric astigmatic eyes, the meridian of greatest curvature of the right eye at 135° and that of the left eye at 45°. The same rectangular figure is held before these eyes as was held before the symmetric astigmatic eyes shown in Plate XXXVIII. In Plate XXXIX. there is, on each retina, a distorted image —a non-rectangular parrallelogram image—and the dis-

tortion is in opposite directions. With either eye alone, the rectangle will appear to be a non-rectangular parallelogram. The one seen by the right eye would lean down to the left; and the one seen by the left eye would lean down to the right. To fuse such images even imperfectly, the fusion faculty of the mind must cause the right and left six basal centers to send neuricity to their respective superior obliques. These muscles responding cause a compensating minus cyclotropia, and the fusion of the two images results not in showing the figure as a rectangle nor as a non-rectangular parallelogram, but as a trapezoid, *a b c d′*. The cyclotropia of the right eye has brought the upper and lower borders of the figure seen by it into the horizontal, but the two ends are not vertical, though parallel. This figure, which is a part of the fused figure, is *a, b, c, d*. The cyclotropia of the left eye has placed the horizontal meridian parallel with the upper and lower borders of the image, but the ends are further from being parallel with the now inclined vertical meridian. The figure seen, which is a part of the fused figure, is *a′ b c d′*. The plate shows a perfect fusion of the lower border of the figure, an incomplete fusion of the upper border, but no fusion at all of the ends. The imperfect fusion of the two non-rectangular parallelograms develops the perfect trapezoid, the very best that such eyes can do in the way of fusion of the dissimular images. The plate shows that the two superior

obliques have made the two horizontal meridians dip down and in, and have made the two vertical meridians incline towards each other. The dipping horizontal meridian in each eye is thus made parallel with the upper and lower borders of the distorted image, hence the corresponding borders of the figure appear horizontal. The vertical meridian, however, is not so nearly parallel with the two ends of the image as it was before torsioning occurred, hence the two ends of the fused object are far from being vertical. The right border of the fused object is seen by the right eye only, and is inclined from the median plane of the head; the left border of the fused object is seen by the left eye only, and is inclined from the median plane. Thus the trapezoid has its longer side at the top.

The trapezoid would be inverted if it were seen by non-symmetric astigmatic eyes, whose meridians of greatest curvature converge above—that of the right being at 45°, and that of the left at 135°. The distorted images in such eyes would be fused by the action of the right and left seventh basal centers on the inferior obliques, as illustrated in Plate XXXVII. In each of these eyes the parallelogram image would dip down and out, and the plus cyclotropia would make the horizontal meridian dip down and out just enough to make it parallel with the upper and lower borders of the image. This compensating plus cyclotropia

would make a rectangle appear to be a trapezoid with the longer side below.

Referring again to Plate XXXIX,, the result of the correction of the astigmatism would be the correction of the distortion of the image in each eye; that is to say, the rectangular object would have a rectangular image, the upper and lower borders of the image being parallel with the horizontal meridian, and the end borders would be parallel with the vertical meridian. With the one eye covered, the other eye would see the figure as it is—a rectangle, and in its true position; for in monocular vision, with or without the correcting cylinder on, the sixth basal center, for that eye, will become quiet, thus allowing the vertical axis of the eye to become parallel with the median plane of the head. This would be true of either eye alone. But the moment that binocular vision, through the correcting cylinders, is attempted, the right and left sixth basal centers, from long habit, will send neuricity to the superior obliques. The result will be to make the rectangular figure appear as a trapezoid, the longer side being below. From infancy the patient has been accustomed to the trapezoid shape of a rectangle, the longer side above, and may not be able to detect it when questioned as to its shape; but when, because of a continuance of the fusional activity of the two sixth basal centers, the correcting cylinders are made to distort the rectangle into a trapezoid, longer side below, the change

is observed at once. The opposite wall of a room will appear to lean from him, and the floor will appear to slant towards him. These changes are more or less annoying to all patients unless they are told about them beforehand. When the eyes are like those in Plate XXXIX., the patient can be assured, nearly always, that these annoyances will disappear within two or three days. It is a matter of observation that the habit of fusional activity of the right and left sixth basal centers and of the two superior obliques is soon given up, when the necessity for it has been removed; and the moment the habit is broken a rectangle appears as a rectangle, the floor becomes level and the wall becomes vertical. After having become accustomed to the normal condition of external objects, as seen through correcting cylinders, on removing the lenses the patient will say that a rectangle is longer at the top than at the bottom, that the floor slants from him, and that the wall leans towards him.

The correcting cylinders of astigmatic eyes, whose meridians of greatest curvature converge above, are more annoying, and for a longer time, than when these meridians diverge above. The only explanation, as to the longer duration of the metamorphopsia, is that the right and left seventh basal centers, and the strong inferior obliques, are slow to give up their habit of fusional activity, even after the necessity for such activity has ben removed. Even in

these cases, if the axes of the cylinders have been carfully and correctly placed, the patient can be assured that, in a week or two, a rectangle will cease to appear longer at the top; that the floor will continue to rise at the wall, until it becomes level; and that the wall, at the floor, will continue to approach him until it becomes perfectly vertical.

Again, it may be said that the correcting cylinders of symmetric oblique astigmatism never causes metamorphopsia, nor does the correction of vertical and horizontal astigmatism cause it, and for the simple reason that neither the right and left sixth, nor the right and left seventh, basal centers have ever been excited, by these conditions, into fusional activity, hence they never have formed a habit that must be broken. Both with and without the correcting cylinders, the obliques of such eyes simply maintain parallelism between their vertical axes and the median plane of the head, and, if orthophoric, they do this without activity of a single basal center.

There is work done by nerve centers and by the two muscles in the ciliary body, common to all forms of hyperopic astigmatism—both the symmetric and the non-symmetric—in both distant and near vision; also common to all forms of low myopic astigmatism, in near work. The Muller muscles and the conjugate center (the tenth) controlling them, are active, doubtless; but the best they can do is to relate the two foci, to the rectina, so that the one shall

be just as far in front of it as the other is behind it. In unequal astigmatism, one of the tenth basal centers, doubtless, is active also.

That another natural provision has been made for the correction, in part or wholly, of astigmatism would appear from the anatomic nature of Bowman's muscle in the ciliary body. If the fibers of this muscle, running meridionally, effect any change in the power of the lens, it must be by tilting it. It is well known that tilting a lens increases its power at right angles to the axis of the rotation. Since the aim of the lenticular astigmatism, thus produced, must be the correction of a corneal astigmatism, the axis of the lens rotation must lie in a plane with the meridian of greatest corneal curvature. The rotation power must reside in the Bowman muscle; the contracting fibers must be in a single part of that muscle, and this part must be situated on only one side of the plane of the axis of rotation, and just 90° from it. It could be on either side. The anatomic arrangement of the fibers of Bowman's muscle is such that physiologic activity might be excited in one part while all other parts are at rest. This muscle is presided over, probably, by the superior cervical sympathetic, as are the radiating fibers of the iris. However this may be, it is certain that the nerve endings, controlling Bowman's muscle, cannot be influenced by atropia or any other known drug. Hence it is impossible, in many cases,

to uncover all the corneal astigmatism with any agent that will put at rest the Muller muscle. In time, the power of the Bowman muscle wanes, as does that of the Muller muscle, and then the full amount of corneal astigmatism becomes manifest.

In adjusting astigmatic lenses, there is no excuse for not suspending the power of the Muller muscle, and thus make the eye show whether the astigmatism is mixed or hyperopic, notwithstanding the fact that no known drug can suspend the neutralizing lenticular astigmatism. A full correction of manifest astigmatism, under a mydriatic, leads to a further manifestation of corneal astigmatism. Increasing the strength of the cylinder, as more of the real error is thus teased from under cover, in a few years the whole error becomes manifest, and then the full corection of the corneal astigmatism should be given. Future experience must settle the question: "Would it be well to fully correct the astigmatism shown by the ophthalmometer, although, temporarily, the patient's vision might be made less acute?" Astigmatism *per se* may be corrected by either + or — cylinders, but the kind of cylinder to be given, and whether or not it shall be associated with a sphere, can be determined accurately only when the eyes are under the influence of a mydriatic. The mydriatic does not change the distance between the two foci (only the two principal meridians have foci), but it fixes accurately the

static relationship that the anterior focus bears to the retina. Bowman's muscle influences the posterior focus only. With the anterior focus located where static refraction would place it, the astigmatic error can be corrected intelligently; otherwise, any effort at correction is only guess-work.

A full correction of corneal astigmatism relieves the tenth conjugate center and Muller's muscles from abnormal work; it also brings rest to Bowman's muscle and to the center controlling it, which is, probably, the superior cervical sympathetic ganglion, or a still higher center with which it may be connected. This is the whole relief that comes from the correction of symmetric astigmatism; and this relief would come, to such eyes, as the result of advancing years, if no lenses were ever given. Lenses cut short the suffering that is caused by abnormal work of the centers and muscles mentioned, and also bring pleasure by sharpening vision.

There are brain centers and muscles that must act in uncorrected non-symmetric oblique astigmatism, to which no rest can come because of advancing years. These centers are the right and left sixth, and right and left seventh, basal centers, and the muscles are the superior and inferior obliques. Correcting cylinders alone can relieve the oblique muscles and the basal centers connected with them. Without correcting cylinders, the suffering of those who have

oblique astigmatism is commensurate with the duration of life.

If it is important to correct symmetric oblique astigmatism, and vertical or horizontal astigmatism, it must appear doubly important to correct non-symmetric oblique astigmatism.

Metamorphopsia.

The metamorphopsia caused by the wearing of fully correcting plus cylinders, when the axes are in the upper temporal quadrants, or minus cylinders with axes in upper nasal quadrants, is so transient, in most cases, that nothing need to be done to modify it. Occasionally, however, such a patient is so much annoyed something must be done other than making the declaration that these troubles will pass away, under the persistent wearing of the lenses.

The metamorphopsia is so prolonged and disagreeable, when the axes of plus cylinders are in the upper nasal quadrants, or when the axes of minus cylinders are in the upper temporal quadrants, something must be done to modify it. Otherwise many patients would discard their lenses. There are two methods of procedure, either one of which may be adopted successfully. One is the Lippincott method, which is to give only a partial correction (about one-third) of the manifest astigmatism, at the beginning. This causes but slight metamorphopsia, which soon vanishes; and then

still stronger cylinders, a two-thirds correction, are given. The slight metamorphopsia caused by the new lenses soon disappears. Now the full strength cylinders may be given, with a resulting metamorphopsia both slight and transient. By this method the breaking of the habit of brain centers and muscles is easily accomplished, and with but little annoyance to the patient. This method is not often applicable to astigmatism in which the meridians of greatest curvature are in the upper temporal quadrants.

The other method is the shifting of the axes of the correcting cylinders, in the direction of the continued torsioning, sufficiently far to make the slanting floor almost level. At intervals of two or three days the axes should be moved slightly towards the degree mark selected in the monocular tests, which point should be reached at the third or fourth backward shifting. By this method the habit of brain centers and muscles is as easily broken as by the Lippincott method. The cost of changing lenses two or three times is the only objection to the giving of partial corrections, in suitable cases.

The following simple rule may be given for the shifting of both plus and minus cylinders for lessening metamorphopsia: *The axes of plus cylinders, whether in the upper temporal or upper nasal quadrants, should be shifted towards their respective verticals; the axes of minus cylinders, whether in the upper nasal or upper temporal quad-*

rants, should be shifted towards their respective horizontals. The shifting should be only so far as to almost level the floor; and by degrees, these axes should be returned to the points on the arcs determined for them, by both ophthalmometer and trial lenses, in the monocular tests.

For emphasis it may be stated again that, for lessening metamorphopsia, plus cylinders will require shifting rarely, if their axes are located in the upper temporal quadrants; and that minus cylinders, with their axes in the upper nasal quadrants, will need shifting just as infrequently. In either case the right and left sixth basal centers and the two superior oblique muscles learn speedily to suspend their efforts to maintain the minus cyclotropia formerly required by the fusion faculty. Astigmatics, who have been punished by the necessity for compensating minus cyclotropia, nearly always enjoy their correcting cylinders from the beginning.

The astigmatic condition requiring that the axes of plus cylinders shall be in the upper nasal arcs, or that the axes of minus cylinders shall be in the upper temporal arcs, when uncorrected, made it necessary for the right and left seventh basal centers to force the inferior obliques into fusional activity. Because these centers and muscles are slow to give up their work of cyclo-duction, even after the need for it no longer exists, the axes of the cylinders should be shifted according to the rule given above, the only purpose

of the shifting being to lessen the metamorphopsia, and minimize the annoyances while the habit is being broken.

Artificial Causes of Compensating Heterotropia.

Prisms.—A prism placed base out before an eye demands that there shall be a compensating esotropia, otherwise there would be diplopia. If the eye is esophoric, the excessive tonicity of the internus may turn it in sufficiently to effect fusion. If so, the prism thus placed, instead of exciting the third basal center and causing the internus to contract, brings rest to the fourth basal center and the externus, previously at work to counteract the esophoria. Before such an eye the prism would do good, and not harm.

The same prism, similarly placed before an orthophoric eye, would excite into activity the third basal center, which would cause the internus to turn the eye in, by its contractile power. By creating a necessity for fusional activity of a basal center and the muscle controlled by it, the prism would be a bad thing, and would cause suffering.

The same prism, similarly placed before an exophoric eye, would be more hurtful still; for it would increase the demand on the third basal center and the internus, already engaged in the work of counteracting the exophoria.

A prism, base out, will do good if the eye is esophoric, will do harm if the eye is orthophoric, will do greater harm

if the eye is exophoric. In all three instances there has been developed a compensating esotropia, but in the first instance the esotropia was effected by tonicity; in the two other instances by contractility, effected by an excited basal center.

For the same reason, a prism, base in, will do good if the eye is exophoric, but will do harm if the eye is orthophoric or esophoric.

A prism, base down, will help a hyperphoric eye, but will be harmful to an orthophoric or a cataphoric eye.

A compensating heterotropia which is effected by muscle tonicity is a good thing; but a compensating heterotropia which must be effected by brain activity and muscle contraction is a bad thing.

The compensating heterotropia, caused by either natural or artificial conditions, may be effected by muscle tonicity, but more often is effected by muscle contractility. The compensating heterotropia effected by muscle tonicity should be allowed to continue; but the cause of a compensating heterotropia which is effected by brain activity and muscle contraction should be removed.

One of the most common and hurtful causes of compensating heterotropia is the incorrect wearing of lenses which, in themselves, may be perfect. Convex lenses for either hyperopia or presbyopia, and concave lenses for myopia, should be so placed before eyes as not to excite fusional

activity of basal centers and muscles; and if such activity exists without lenses it should be relieved by them, if possible.

If eyes are orthophoric, convex or concave lenses should be in frames of a width corresponding to the distance between the pupillary centers, and should be perfectly level. Thus worn, no basal center will be excited nor will any muscle be made to do abnormal work. Should convex lenses be in frames that are too wide, or concave lenses be in frames that are too narrow, the right and left third basal centers, and the interni, must be continually active in the production of compensating esotropia. Should convex lenses be in frames that are too narrow, or concave lenses in frames that are too wide, the right and left fourth basal centers and the externi must be continually active in the production of compensating exotropia. When spectacles lean to the right, if they contain convex lenses, the right first basal center and its superior rectus muscle must take on fusional activity, and the left second basal center and its inferior rectus must become active also. If spectacles, leaning to the right, contain concave lenses, the right second basal center and its inferior rectus, and the left first basal center and its superior rectus, must all become active in the interest of fusion.

Only in esophoria should convex lenses be wider apart, and concave lenses closer together, than the pupillary meas-

urement calls for, the justification for this being the relief they bring to the right and left fourth basal centers and the external recti, by the development of a tonicity compensating esotropia.

Only in exophoria should convex lenses be closer together and concave lenses wider apart than indicated by the pupillary measurement, and for the reason that, thus related, they would relieve the right and left third basal centers, and the interni from fusional activity.

Convex lenses in frames inclined to the right, before orthophoric eyes, must cause diplopia, unless this is prevented by activity of the right first basal center and its superior rectus, in the production of compensating right hypertropia, and of the left second basal center and its inferior rectus, in the production of compensating left catatropia. So long as the frames are thus leaning, these centers and muscles, which ought to be at rest, will be forced by the fusion faculty to continue this abnormal activity. Symptoms of some character must arise, for, soon or late, these centers and muscles will rebel, and, in their rebellion, will have the sympathy of other centers, basal or cortical. The remedy is the leveling of the lenses.

If a patient has right hyperphoria, the leaning of frames, containing convex lenses, to the right will cause a tonicity compensating right hypertropia and left catatropia, which will relieve the right second basal center and its inferior

rectus, and the left first basal center and its superior rectus; but the leaning of the frames to the left would make the lenses unbearable, by compelling the centers and muscles named to do additional work.

The oculist cannot be too careful in adjusting frames that will contain lenses he may have prescribed; nor should he be remiss in his duty to his patients, by failing to impress them with the importance of keeping the lenses properly related to the eyes.

Cylindric Lenses.—The only remaining artificial cause of compensating heterotropia is the cylindric lens. Eyes that are not astigmatic can be made so by either convex or concave cylinders. The astigmatism they produce is symmetric if the cylinders are of the same kind, equal in strength and their axes are parallel. Otherwise, the artificial astigmatism would be non-symmetric. In symmetric artificial astigmatism, images must be blurred more or less, but there will be no cause for compensating cyclotropia, hence there would be no activity of either the right and left sixth basal centers and their superior obliques, or of the right and left seventh basal centers, and their inferior obliques.

Artificial astigmatism produced by convex cylinders whose axes are in the upper nasal arcs, or by concave cylinders whose axes are in the upper temporal arcs, will have images so distorted as to produce diplopia which can be

prevented only by compensating minus cyclotropia. This work must be done by the right and left sixth basal centers acting on the two superior obliques.

In artificial astigmatism produced by convex cylinders whose axes are in the upper temporal arcs, or by concave cylinders whose axes are in the upper nasal arcs, images will be so distorted as to call into fusional activity the right and left seventh basal centers and the inferior obliques. So long as the cylinders, thus placed, are in front of the eyes, compensating plus cyclotropia must be maintained. Orthophoric obliques, and their centers, cannot endure this work, hence such lenses, however obtained, would be cast aside.

Compensating cyclotropia, effected by tonicity of the obliques, relieves, rather than excites, basal centers; hence the production of artificial non-symmetric astigmatism is justifiable when there is cyclophoria, provided other treatment will not be acepted. In plus cyclophoria, as illustrated in Plate XXXVI., the right and left sixth basal centers and the two superior obliques are acting in the maintainance of parallelism of the vertical axes of the eyes with the median plane of the head. If plus cylinders, with their axes in the upper temporal arcs, or minus cylinders with their axes in the upper nasal arcs, are placed before these eyes, images will be displaced so as to excite compensating plus cyclotropia. This would be effected by the tonicity of the strong inferior obliques; and the right and left sixth

basal centers and the weak superior obliques would be given rest. In such a case, should the axes of the cylinders be reversed, those of plus cylinders in the upper nasal arcs, and those of minus cylinders in the upper temporal arcs, they would become unbearable, for they would compel a compensating minus cyclotropia. This could be effected, not by tonicity of the superior obliques, but by excessive contractility. This added burden cannot be borne by the right and left sixth basal centers and the two superior obliques.

Whether the artificial non-symmetric astigmatism be of one kind or the other, the images are equally blurred; but in the kind exciting tonicity plus cyclotropia, there is comfort, while in the kind exciting contractile minus cyclotropia there is great discomfort. In the former there is no excitement of basal centers, nor is there contraction of the obliques; in the latter, the right and left sixth basal centers must be active and the two superior obliques must be contracting.

Cylinders given for the correction of either symmetric or non-symmetric astigmatism, may be made to produce an artificial astigmatism and thus create a compensating cyclotropia. This is accomplished by shifting the cylinders so that their axes are no longer in planes with the meridians of greatest curvature, if the cylinders are plus; or least curvature, if the cylinders are minus. If the obliques are

orthophoric, any displacement of the axes of the cylinders, in opposite directions, will excite either the right and left sixth basal centers and the superior obliques; or the right and left seventh basal centers and the inferior obliques, the direction of the shifting determining whether it shall be the one set of centers and muscles or the other. If there is a plus cyclophoria a certain shifting of the cylinders will cause a compensating plus cyclotropia which would be effected by tonicity of the inferior obliques. This would relieve the right and left sixth basal centers, and the superior oblique muscles, of the work of counteracting the cyclophoria. The comfort that follows is a full justification of the procedure. Had the axes been shifted in the opposite direction, in this case, the change would have been hurtful, in that it would have demanded of the already over-worked sixth basal centers, and the weak superior obliques, the production of a compensating minus cyclotropia.

If there is orthophoria of the obliques, the axis of a cylinder should never be rotated out of the plane of the principal meridian before which it stands, for the reason that a basal center and an oblique muscle would be excited by such shifting. If there is a plus or minus cyclophoria (the former is common, the latter is uncommon), correcting cylinders may be shifted, but only in the direction that will relieve the basal centers and the oblique muscles which have always been active in counteracting the cyclophoria. It is

not going too far to say that the axes of correcting cylinders should be shifted when there is cyclophoria, unless this condition can be relieved by exercising the weak obliques, or by curing the condition, in suitable cases, by operating on a rectus muscle.

When the axes of cylinders are shifted to relieve cyclophoria, they must be allowed to remain at the new points always, that the effects may be permanent. When axes of cylinders are shifted to relieve the patient of annoying metamorphopsia, the aim should be to return the axes to their proper places, by degrees, and as soon as possible. Not only is the purpose of the shifting, for cyclophoria, different from the purpose of the shifting, for metamorphopsia, but the rules, by which the changes are made, differ also. The rule to follow when there is metamorphopsia can be found on page 196. Dr. N. C. Steele, of Chattanooga, a life-long friend of the author, and himself an earnest student of the ocular muscles, has remodeled his rules for shifting cylinders for the relief of cyclophoria, as published in *Ophthalmic Myology*. The author requested Dr. Steele to allow him to publish, in this chapter, his "working rules," which are clear and simple. These are the Steele rules:

"(1) *In oblique hyperopic astigmatism, simple or compound, in which there is plus cyclophoria (weak superior oblique muscles) and the upper end of the best meridian of*

either or both eyes is anywhere in the upper nasal quadrant, and you are in doubt as to the exact point (degree) at which to place the axis of the plus correcting cylinder, you should place it as far from the center of that quadrant as the tests will permit.

"*If all your tests have indicated one point (degree) as the correct one for the axis of the cylinder, it is advisable to shift the axis two to five degrees further from the center of the quadrant—upper nasal, or, what is the same thing in effect, the lower temporal quadrant.*

"(2) *In oblique hyperopic astigmatism, simple or compound, in which there is plus cyclophoria (weak superior oblique muscles) and the upper end of the best meridian of either or both eyes is anywhere in the upper temporal quadrant, and you are in doubt as to the exact point (degree) at which to place the axis of the plus correcting cylinder, you should place it as near the center of that quadrant as the tests will permit. If all your tests have indicated one point (degree) as the correct one for the axis of the cylinder, it is advisable to shift the axis two to five degrees nearer the center of the quadrant—the upper temporal, or, what is the same thing in effect, the lower nasal one.*

"(3) *In cases having minus cyclophoria (weak inferior oblique muscles) the foregoing two rules should be reversed.*

"(4) *In oblique myopic astigmatism, simple or compound, all the three foregoing rules should be reversed.*

"(5) *In mixed oblique astigmatism the first two rules hold good when plus correcting cylinders are prescribed, but when minus correcting cylinders are prescribed they should be reversed.*

"All of the above rules apply to cases in which there is oblique astigmatism in both eyes, and in cases with oblique astigmatism in one eye and vertical or horizontal astigmatism in the other, and in cases with oblique astigmatism in one eye and no astigmatism in the other."

Vertical and horizontal astigmatic errors are often associated with plus cyclophoria, sometimes with minus cyclophoria. The correcting cylinders, in these cases, should be shifted for the developing of a cyclotropia that will cure the cyclophoria. *If there is plus cyclophoria, and all the monocular tests have shown that the best meridian of each eye is at either* 90° *or* 180°, *the correcting plus cylinders should have their axes shifted two to five degrees into the upper temporal arcs, or the correcting minus cylinders should have their axes shifted two to five degrees into the upper nasal arcs.*

The above rule is all that the author would add to the Steele rules; nor does he see that anything should be eliminated from these rules.

If there is no cyclophoria complicating a case of astigmatism, any displacement of the axes of the correcting cylinders, or any error made in adjusting them, would excite

basal brain centers and the oblique muscles under their fusional control. Discomfort would as certainly result as that night follows the day. Nothing could emphasize more strongly the fact that all astigmatic eyes should be examined under the most favorable conditions, and that all available practical means should be used in locating the principal meridians, and in determining the kind and quantity of the error. These are the favorable conditions: The eyes should be under the influence of a mydriatic, and each eye should be tested while the other eye is covered. The mydriatic gives the static relationship of the anterior focus to the retina. The monocular test guarantees that the vertical axis of the eye under test is parallel with the median plane of the head. The best means for locating the anterior pole and the axis of the cylinder, is the ophthalmometer; and the best means for determining the strength of the cylinder and whether it shall be plus or minus, are retinoscopy and the trial lenses. Although indispensable in detecting intraocular diseases, the ophthalmoscope can help but little in the work of refraction, statements to the contrary notwithstanding. Last, but not least in importance, is the perfect adjustment of the spectacle frames. Patients should always be told that a straight-edge should pass through the four joints of the frames, and that the temple pieces should be adjusted so as to prevent an inclining of the frames. It is a matter for regret that nose-glasses were

ever invented, for the reason that it is so hard to keep them properly adjusted.

One thing deserving emphasis, in closing this chapter, is the fact that the man or woman who assumes to correct errors of refraction and muscle errors should acquaint himself or herself, first of all, with human anatomy and physiology, and especially with that most wonderful and complicated part of man, the nervous system, which presides over the nutrition, and controls the function, of every other organ and part. Nor should he stop with a perfected knowledge of anatomy and physiology, but he should acquire a knowledge of general and special pathology, of symptomatology, of chemistry, of materia medica and general and special therapeutics. In other words, he or she should be required to complete a graded course of study, covering four years, in a reputable medical college; for correcting errors of refraction, and muscle errors, is as much a part of the practice of medicine, as is the treating of a case of pneumonia or the setting of a broken bone.

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